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CONTENTS

G. ap Griffith: Factors influencing Nitrate Accumulation in Uganda Soil 1

L. G. Vallance: Recent Advances in Sugar-cane Culture in Queensland. With Plate 1 13

R. E. Altona and N. J. Mentz: The Control of Weeds in Maize with Selective Plant-growth Regulators 26

D. J. Halliday and W. G. Templeman: Field Experiments in Selective Weed Control by Plant-growth Regulators. III. Weed Control in Grassland 33

G. Haskell and P. Dow: Studies with Sweet Corn. V. Seed-settings with Distances from Pollen Source 45

S. Bartlett, E. S. Baxter, R. Braude, and K. G. Mitchell: The Nutritive Value of Conophor Cake-meal for Young Dairy Stock and Fattening Pigs 51

G. P. Hughes and T. A. Evans: Response of an Established Sheep Ley to Dressings of Sulphate of Ammonia. Pt. I. Yields and Botanical Composition of Herbage cut for Silage and for Hay 55

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FACTORS INFLUENCING NITRATE ACCUMULATION IN UGANDA SOIL

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(*Uganda Department of Agriculture*)

EARLIER work in Uganda has indicated that under some conditions nitrate nitrogen accumulates in notable quantities in the soil. Fluctuations in soil nitrate have been widely recorded from many countries, but the first results here have differed in some respects from those reported elsewhere. Later work reported in this paper bears out the earlier results and indicates the importance of a proper study of phenomena that are clearly of both agricultural and pedological importance.

Review of Literature

In 1916 Gainey [1] reported quantities of NO_3 of over 500 lb./acre and Fred and Graul [2], in laboratory nitrification tests, found closely similar quantities after one year. Greaves and Carter [3] in a summary of the literature showed that the optimum moisture-content for nitrate formation seemed to vary with the nature of the soil, less water being necessary in light soils. By many workers 14–18 per cent. was regarded as an optimum with 10 per cent. the lower limit and 25 per cent. the upper; about 50 per cent. of the water-holding capacity seemed to be the optimum; the optimum for nitrification was somewhat lower than that for ammonification.

Hall [4], comparing South African results with those reported from America and from Rothamsted, concluded that nitrification in South African soils was not exceptionally active. He found that the nitrate figures followed the rainfall and not the temperature. The same author [5] reported figures for NO_3 up to 180 lb./acre-foot and said that the seasonal variation showed a nitrate production that would be adequate for most crops, and that it served to throw light on poor results from added nitrogenous fertilizers.

Russell, Jones, and Bahot [6] stated that NO_3-production was slow at 5° C., increased rapidly with rising temperature to a maximum at 35° C., and ceased at 55° C. It was insignificant at a moisture-content as low as the hygroscopic coefficient, but increased up to the highest degree of wetness studied, namely $1\frac{1}{4}$ times the moisture equivalent, or 26 per cent.

Albrecht [7] reported the failure of soil under mulch to increase in NO_3 and suggested either a moisture or temperature effect. Albrecht and Uhland [8] said that the failure of NO_3 to accumulate under a mulch was not due to a shortage of ammonia nitrogen as this was in fact higher under the mulch. Removing the mulch gave a marked increase in NO_3 after 2 months, whilst application of mulch to a soil brought a marked decrease in the same time. (These latter statements lose much of their value as the climatic conditions were not specified.)

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In 1930 Sears [9] found that the speed of NO_3-accumulation was greatest in the soils kept at a low moisture-content and high temperature, whereas least accumulation occurred where moisture was high and temperature low.

Beaumont and Brooks [10] found that the depression of nitrate by mulch continued for 3 years, but during the fourth year nitrate accumulated, often in large amounts. They suggested that nitrification occurred only after the C/N ratio had been narrowed by decay acting on the organic matter of the mulch. They do not state how frequently the mulch was renewed during this period (if at all), or to what depth, and the climatic conditions are not described.

McKay and Baker [11] confirm the finding that the lowest amount of NO_3 was always produced under a straw mulch, but state that the amount was nevertheless always sufficient for optimum crop production.

Hardy [12] found that, contrary to the general view, nitrate accumulated under conditions of extreme dryness in Trinidad. The figures he reports range up to about 60 p.p.m. of nitrogen (= $264NO_3$). Similar quantities have been reported from Queensland by Hodge and Cowdry [13], who refer to them as excessive and as necessitating special cultural methods for their reduction.

Pran Kumar De and Sachindra Nath Sarkar [14] reported the rapid loss of nitrate under waterlogged and wet conditions and stated that the loss was caused by the assimilation of NO_3 by micro-organisms and not by reduction to ammonia.

Batham and Nigam [15] reviewed the results from various parts of the world, and showed that the general conclusion was a close relationship between fluctuations of NO_3 and season. From these results and from their own data they concluded that solar activity is a most important factor in controlling the nitrifying activity of soils.

Mortenson and Duley [16] showed increases in NO_3 due to treatment with ultra-violet light. Photochemical explanations of nitrate formation have also been strongly advocated by some Indian workers such as Rao [17] and Tandon and Dhar [18]. Their theories have been equally strongly criticized by Waksman and Madhok [19], who point out with some justice that Dhar's hypothesis of photochemical oxidation presupposes the prior formation of NH_3, so that it does little to explain the ultimate source of the accumulated nitrogen.

Preliminary results in Uganda, reported by Griffith and Manning [20], show that grass mulch markedly depresses nitrate formation, and a time-lag of several weeks occurs after removal of the mulch before NO_3 begins to increase. Nitrate production is markedly correlated with season, a steep rise in NO_3 occurring with the onset of rains. Nitrate on grassland (*Pennisetum purpureum*) was at a low level and remained low throughout the first year of cultivation after ploughing.

The most striking aspect of the earlier Uganda figures was the magnitude of NO_3-accumulation under bare fallow conditions. Figures of 100 p.p.m. were common and peak figures of over 400 p.p.m. were recorded. Thompson and Coup [21] report similar high figures in New

Zealand [21], but seek the explanation, it is thought unnecessarily, in local contamination by stock urine.

In contrast with these high figures are those reported from Queensland and Trinidad, and those recorded over many years of study in Gezira (Anglo-Egyptian Sudan). Typical analyses quoted in *Agriculture in the Sudan* (Oxford University Press, 1948) range from 5 p.p.m. in the top foot to 40 p.p.m. in the sixth foot. These results are expressed as nitrogen; the NO_3 figures are 22 p.p.m. and 176 p.p.m. respectively. The figure for the top soil, however, is still low. Earlier work in the Sudan showed that irrigation gave a general increase in the amount of nitrate, but this gradually disappeared as the land dried. This agrees with the findings of most other workers, but it contrasts with the results reported from Trinidad by Hardy. Later work in the Sudan showed the method of cropping had a marked effect on the nitrate values. Considerable accumulation of nitrate at depth is reported in the Sudan records, and a similar accumulation is reported from Kenya by Gethin Jones in an unpublished communication. Another significant feature of the Sudan work is the rapid increase in nitrate following the hoeing of weeds on resting land, the accumulation persisting until the following year and being reflected in a greatly increased yield of cotton.

Experimental Work at Serere and Kawanda

It was thought advisable to repeat at Serere the simple observations, made first at Kawanda in 1949 [20], on a different soil and under somewhat different climate. Observations were continued into their second year on land opened from elephant grass at Kawanda in 1948, whilst observations were started on land newly opened from grass at Serere. Finally, a more elaborate series of investigations was begun at Kawanda.

Serere (*1° 30′ N. 33° 30′ E*). A plot was laid out with alternating strips of grass mulch (*Imperata cylindrica*) and of bare soil. Samples were taken weekly for moisture and nitrate determinations, the latter carried out by distillation with Devarda's alloy after preliminary boiling with magnesium oxide [22]. The determinations were all carried out at Serere on fresh samples. Weekly observations were also made on land newly opened from *Imperata cylindrica* (referred to henceforward as 'grass'). The soil is a light loam with pH a little over 6, with exchangeable base-content of about 13 m.e. per cent., and a Truog soluble phosphate of 50 p.p.m. The rainfall is some 10 in. more than at Kawanda, about 53 in., but maximum temperatures are much higher and the dry seasons are longer and more severe. It will be seen from the diagram (Fig. 1) that the moisture on the bare soil falls during the dry season to the low figure of about 2 per cent.

Kawanda.—Observations are now being made on an area laid out in eighteen 1/30-acre plots in three adjacent rows of six; one row is kept bare under artificial shade (poles 4 ft. high, supporting a flat roof of grass canes), one row is bare unshaded, and one row, otherwise unshaded,

planted with a succession of crops. In each row one plot receives in terms of lb./acre of NO_3: nitrate of soda 440, one sulphate of ammonia 440, and one kraal manure at 10 tons/acre; there are also two untreated plots and one which is kept mulched with grass (*Imperata cylindrica*) to a depth of 6 in. All plots are protected from each other

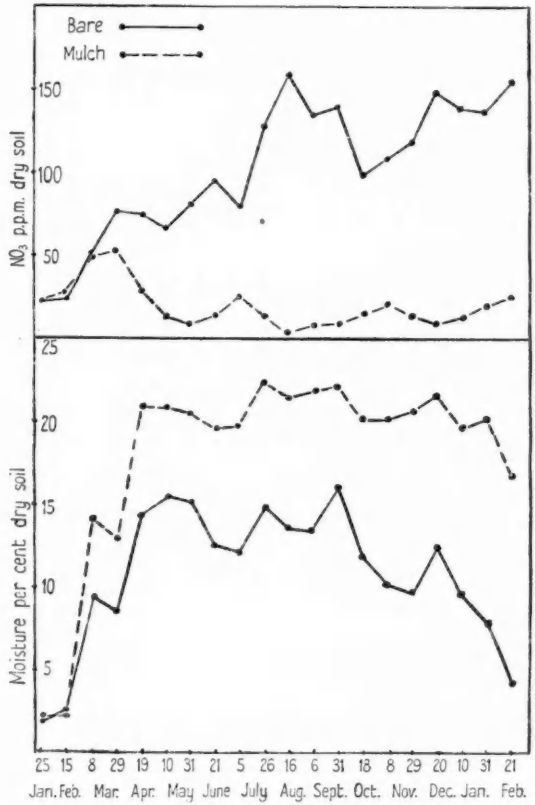

FIG. 1. Nitrate in bare and in mulched soil at Serere, Uganda. (Three-weekly means.)

by bunds planted with *Paspalum notatum*. The cropped plots were planted on April 1 with eleusine, which was harvested in the first week of August, when cotton was planted. (Cotton was harvested in January and uprooted in early February.)

Weekly sampling has been carried out on these eighteen plots for determining nitrate and moisture, all determinations being made on fresh samples. Fig. 2 summarizes the 3-weekly means of the results for about a year. Observations were confined to the top 6 in. to economize labour and materials, as earlier work had shown that the curve for

the second 6 in. followed closely that for the top 6 in. As soon as possible it is intended to extend the observations to lower depths.

The soil is a light loam, pH about 5·0, with an exchangeable-base status of less than 10 m.e. per cent. It is poorer and more acid than the soil of the site where the earlier work was carried out. Mulch was applied on March 23, and the kraal manure and fertilizers on April 1. On April 2 and 3 unusually heavy rain fell to mark the beginning of the wet season—over 3 in. in 24 hours. A failure in the supply of reagents made it impossible to carry out determinations for 3 weeks after the date of application, so that much information may have been lost at the outset.

In addition to these eighteen plots weekly observations were made on land opened up from elephant grass now in its second year of cultivation.

Discussion of Results

Mulch: Serere and Kawanda.—The results at Serere are similar to those obtained in the previous season at Kawanda (Fig. 1). Nitrate production starts immediately with the onset of the rainy season on the bare soil. Under mulch, though there is an initial small rise when the moisture-content rises above 30 per cent., this is followed by a fall, after which the nitrate-content under mulch, though fluctuating slightly, remains at a low level. At Kawanda mulch depressed the nitrate throughout the season on all plots (Fig. 2).

Land opened from grass: Serere and Kawanda.—Nitrate under grass at Serere was of the order of 5 p.p.m.; when the land was opened up this rose to between 10 and 20 p.p.m. but remained at this low level throughout the season, thus repeating the course of events reported at Kawanda under *Pennisetum purpureum* in the first season. In the second year from opening up from *P. purpureum* at Kawanda the nitrate changes began to follow the recognized course, namely a steep rise to 150 p.p.m. with the onset of rains. Hodge and Cowdry [13] in Queensland report a similar stepping up of nitrate production in the second and third year of cultivation.

Fuller discussion will be deferred until observations have continued for another season at Kawanda, thus completing the rotation.

Sulphate of ammonia: Kawanda.—By the time determinations were possible the sulphate of ammonia plots stood at some 30 p.p.m. NO_3 higher than the corresponding control plots, and they maintained this difference throughout the year. The quantity applied corresponded to over 200 p.p.m. NO_3 in the top 6 in. Differences between the quantities determined on sulphate of ammonia plots and on the control plots never approached this figure, but the losses may have been due to the heavy rain that followed the application. The curve for the shaded plot is different in pattern from those for the shaded plots under the other treatments. A rise, due to conversion of ammonia into nitrate, is maintained for some months before the nitrate-level falls to the general shade-level.

Nitrate of soda: Kawanda.—Similar comments apply in this case, though in general the amounts of NO_3 are somewhat less and the effect of shade is more immediate.

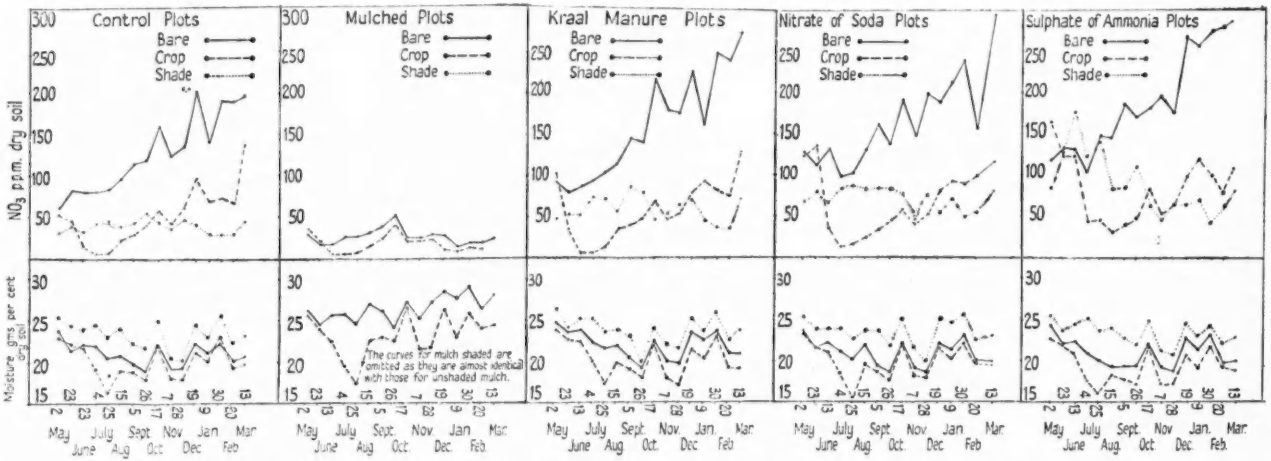
Control Plots
Mulched Plots
Kraal Manure Plots
Nitrate of Soda Plots
Sulphate of Ammonia Plots
Bare
Crop
Shade
NO3 p.p.m. dry soil
Moisture gms per cent dry soil
The curves for mulch shaded are omitted as they are almost identical with those for unshaded mulch.
May June July Aug Sept Oct Nov Dec Jan Feb Mar

FIG. 2. Nitrate in a Kawanda soil under bare, shaded, and cropped conditions. (Three-weekly means.)

Kraal manure: Kawanda.—The kraal manure applied contained 15 per cent. of carbon, total nitrogen 1·5 per cent., and a C/N ratio of 10, compared with one of a little over 11 for the soil under experiment. Ten tons/acre applied was equivalent approximately to an addition of 150 p.p.m. total nitrogen and 1,500 p.p.m. carbon. At an early stage the treated plots took a lead of about 20 p.p.m. over the control plots and by the end of the period reported had increased this lead to about 75 p.p.m. (The artificially shaded plots are also somewhat higher in NO_3 than the controls.) Noteworthy is the slight but steady advantage in moisture-content which the kraal manure plots have over the control.

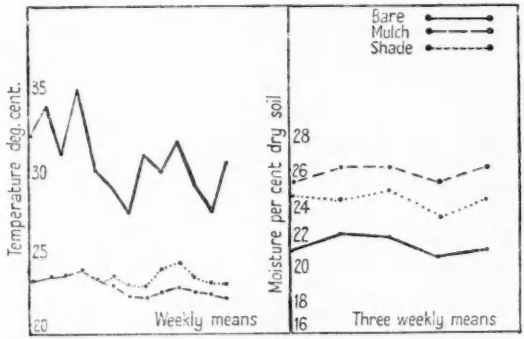

FIG. 3. Temperature and moisture of bare, shaded, and mulched soil at Kawanda (Uganda) March to May.

Note. The curves for bare and mulch are for 1948, that for shade is for 1949.

Shade: Kawanda.—On the control plots shade reduced nitrate formation almost to the level of that under mulch. The small additional depression under mulch may perhaps be due to the shade not being dense and not providing the complete darkness, lack of air movement, or the higher moisture which prevailed under the mulch, although soil temperatures were reduced to the level of those under mulch (Fig. 3).

Thus a definite answer is provided to the question whether the effect of the mulch is due to contact with the soil of a material relatively low in nitrogen or due to its shade effect. Undoubtedly the principal effect is that of shade.

Effect of temperature and moisture.—Apparatus was not available for temperature measurements under the mulch. As the thermometer available had two bulbs only it was not possible to record the temperature on mulch, bare, and shaded plots simultaneously. In 1948, a record of temperatures in mulched and bare soil was kept for three months; in 1949 temperatures under shade and on bare soil were recorded. A recording thermometer was installed at Kawanda to compare the temperature changes under bare and shade conditions. The range of temperature recorded under shade was similar to that observed the previous year under mulch (Fig. 3). Moisture, on the other hand, was appreciably higher under the mulch than under shade (Fig. 3).

Moisture under shade was raised to about 24 per cent.; that under mulch to about 26 per cent. The curves for all the plots suggest that nitrate accumulation is inhibited outside the range 20–4 per cent. moisture. This conclusion refers to the soil of the experimental plots; a somewhat different optimum is indicated for the soil of the land opened from grass. At Serere (Fig. 1) both maximum and minimum moisture-contents are lower, whilst maximum and minimum temperatures are higher. The soil at Serere is lighter in texture than that at Kawanda, and it is to be expected that it is the amount of water above the hygroscopic coefficient which will prove important. Gainey reports a maximum of 24 per cent., and Russell, Jones, and Bahot one of 26 per cent., findings that agree with the Kawanda figures, but it is possible that with a heavier soil a higher limit might prevail.

The present series of observations at Kawanda does not separate the effects of temperature, moisture, and insolation. Under field conditions when temperature is high, moisture is normally lower and vice versa, whilst insolation also varies with temperature and therefore with moisture. A proper separation of these three factors will have to await a controlled experiment in the laboratory.

It is possible, however, to say that temperature *alone* is not the controlling factor. Thus the Serere curves (Fig. 1) show that the nitrate on both bare and mulched plots remained at an identical low level for a period of weeks when the temperature on the mulched plots was some 20° C. lower than on the bare plots, and also lower than that on the bare plots when nitrate production became active. On the other hand, there was an instant response in nitrate production to increased moisture on both mulched and bare plots. Nitrate on the mulched plots kept pace with that on the bare plots until the moisture on the mulched plots rose above 20 per cent., when it fell. When the moisture-content fell below 20 per cent. there was again a slight increase in nitrate, followed by a drop when the moisture again rose over 20 per cent. (The rise in nitrate-content on the mulched plots when their moisture fell below 20 per cent. was matched by a slight check in nitrate production on the bare plots when the moisture fell at the same time to 12 per cent.)

Production of nitrate still occurred though at a lower level, shown by the curve for the cropped, mulched plot (Fig. 2). Nitrate here fell to a level of about 5 p.p.m., but when the eleusine crop had been harvested there was a steady rise to 40 p.p.m. That this rise may be a real one is shown by the curves of almost precisely similar shape on the unmulched plots. In this case, again, temperature changes must have been small, the main change being in the moisture under the mulch, nitrate accumulation continuing until the moisture reached 25 per cent., when it was checked.

Again, the fact that insolation is presumably reduced to zero under the mulch whilst changes in nitrate-content continue, though on smaller scale, shows that the changes are, at least to some extent, also independent of insolation.

Whether these arguments are acceptable or not it remains an important conclusion that determinable quantities of nitrate continue to exist

at the extremes of moisture found both at Kawanda and Serere, and that the agencies responsible for the changes remain to some extent responsive to changes in moisture and temperature at these extremes. Neither under shade nor mulch is nitrate formation completely inhibited; it is merely reduced to a lower level.

The hypothesis is advanced that a soil of given characters (texture, pH, base and humus contents, &c.), under given conditions of moisture, temperature, and possibly insolation, will show a characteristic nitrate-content. Alteration of any factor will alter this characteristic value. Removal of nitrate by a crop will be adjusted to restore the balance unless there is a simultaneous drop in moisture-content. On the other hand, addition of nitrate while other conditions remain the same will only tend to raise the level of nitrate-content temporarily.

In the preceding argument an excessive moisture-content is assumed to inhibit the formation of nitrate. The evidence to be found in the literature justifies this view, but it is necessary to note that moisture-content above field capacity will remove nitrate by downward movement through leaching. In the earlier Kawanda work, it was found that adjacent strips of mulched and bare soil 5 yds. wide were sharply demarcated in nitrate-content down to a depth of 3 ft., demonstrating that downward movement does occur, whilst lateral movement is less marked.

Of importance is the fact that throughout the investigation moisture and nitrate were determined weekly on aliquot samples. In the absence of information on the rapidity with which the nitrate fluctuates it is quite possible that the moisture at the time of sampling may bear little or no relation to the nitrate at the same time. Thus if rain fell 2 or 3 days before sampling, so that the moisture-content was temporarily raised and nitrate production stimulated, by the date of sampling the moisture-content might have fallen whilst the nitrate-content remained at a higher level. To get a clear relation between moisture and nitrate it may therefore be necessary to carry out daily (or even more frequent) sampling for a long period. There is little help to be expected from the rainfall figures as we lack any knowledge of the effectiveness of the rainfall. Under Uganda conditions a fall of 0·25 in. might be as effective as a much heavier but more intense fall.

Finally, if moisture-content affects the nitrate-content this effect will vary with the rapidity with which the soil dries out. Rapid drying may be expected perhaps to leave the nitrate-content unchanged (a fact which is recognized in the laboratory procedure sometimes recommended of rapid drying of samples in order to check changes in nitrate-content).

Relation between crop and nitrate-content.—Three major effects of the crop can be expected: shading of the ground, removal of moisture, and consumption of nitrate. The lowering of nitrate-content is shown in the curves for all plots. Except for a slightly higher figure for sulphate of ammonia the plots show a close similarity in the nitrate-content at crop maturation in July 1949, although initial nitrate-contents were quite different. At the beginning nitrate in the mulch-cropped plot stood at 20 p.p.m. and in the sulphate of ammonia-cropped plot at 140 p.p.m.,

whilst at the harvesting of the eleusine it had fallen to 5 p.p.m. and 30 p.p.m. respectively. A similar comparison can be made between the mulched and nitrate of soda plots. The mulched plot gave, however, a yield of eleusine, grain and straw, higher than that for any other plot with the exception of that treated with kraal manure. The following table gives the yield figures for eleusine and the cotton crop that followed.

Crop	*Sulphate of ammonia* 440 lb. NO_3 per acre	*Nitrate of soda* 440 lb. NO_3 per acre	*Kraal manure* 10 tons per acre	*Control*	*Mulch*
Eleusine, April–July, total yield (grain roots and straw), tons per acre .	9·5	9·0	20·5	9·0	12·0
Cotton, Aug.–Feb., seed-cotton, lb. per acre .	330	309	400	230	940

It is clear that the greater reduction of nitrate in the plots treated with sulphate of ammonia and nitrate of soda is not paralleled by increases in either crop. The eleusine crop from the control plot was found to contain approximately 250 lb. N per acre. For the purpose of the present argument we may assume that amounts proportionate to the size of the crop are removed from the other plots.

The loss of NO_3 from the cropped plots other than that from those treated with nitrogenous fertilizers was much smaller. In this case it is the loss of NO_3 from the top 6 in. only which has been measured whilst the crop has undoubtedly been able to draw on NO_3 from lower depths. On the mulched plot the discrepancy between the amount of nitrate lost during the cropping period of the eleusine and that withdrawn by the crop is too great to be accounted for by supposing the balance to have been drawn from the second 6 in. or lower. We know that the nitrate-level in the second 6 in. under mulch is no higher than that in the top 6 in. Taking into account the depressing effect of the shade cast by crop on the nitrate, the difference between the nitrogen requirements of the crop and the nitrate-content of the soil at any one time becomes even greater. This suggests again that the nitrate-content of the soil at any one moment is an indication of an equilibrium point which if disturbed, e.g. by removal of nitrate by the crop, is re-adjusted.

That the low nitrate under mulch has been adequate for crop needs, though the nitrate-content at any one time is extremely low compared with that taken up by the crop, suggests that under the conditions of temperature, moisture, and insolation under the mulch a low nitrate-content is characteristic, but that as nitrate is consumed by the crop it is replaced sufficiently rapidly both for crop needs and to maintain the characteristic nitrate-level.

At the peak of consumption by the crop there is a marked drop in nitrate-content, but at this point there is also a marked drop in moisture-content. If we accept the hypothesis suggested above that a given

nitrate-content is a characteristic of a given soil under given conditions, then the drop in moisture-content may account at least partly for the fall in nitrate-content.

It has been suggested that under a grass mulch the nitrogen needs of the plant may be met by ammonia or by other nitrogenous compounds. Ammonia determinations made from time to time have shown on all plots, including the mulched, less than 1 p.p.m. of NH_3. This contrasts with the finding of Albrecht and Uhland [8]. Another suggestion that the moisture and other conditions that are reflected in a high nitrate-content, conditions which do not operate as we have seen until the second year of cultivation, may restrict nitrate consumption, whilst the conditions prevailing under mulch may favour nitrate consumption either by the plant or by soil micro-organisms.

Rapidity of fluctuations in nitrate-content.—A characteristic feature of the weekly nitrate curves, which is obscured in the 3-weekly means, is the sharpness of the peaks and troughs. Dr. Herbert Greene in a private communication states that his Sudan results showed a similar effect, but that he had been inclined to regard the sharp rises and drops as due largely to random variation. In the present series of observations this possibility is thought to be excluded as, with few exceptions, the peaks and troughs coincide on all eighteen curves. The appearance of the curves suggests rather two opposing sets of factors at work, one favouring nitrate accumulation, the other favouring nitrate destruction, both rapid in their effect under suitable conditions.

The rises and falls are considerable, often as much as 100 p.p.m. from one week to the next, and it may well be that the rises are in even more rapid response to the stimulus of increased moisture. Future work will be designed to test this point by more frequent sampling. The question whether nitrate disappears into the bodies of the micro-organisms responsible for the changes or in some other way also requires an answer. If the loss of nitrate is due to downward movement, as it must at least be in part, the fact will be of considerable pedological interest as the NO_3-radicle will presumably remove with it the equivalent amount of a basic radicle. Since the quantities of NO_3 concerned may be several hundred pounds per acre in a short time, a profound effect may be exerted on the base status of the soil. Movement of iron and aluminium due to the same cause would also be expected; and deposition at the level where downward movement ceased may provide a contributing factor in the formation of ferruginous and other concretions.

Summary.—Observations on different soils in Uganda indicate that considerable seasonal changes occur in nitrate-content under bare-fallow conditions. These changes are restrained both by grass mulch and by artificial shade. The nitrate-content under mulch at Kawanda has been adequate to produce a crop considerably greater than that grown on an unmulched soil. The nitrate-status is low in the first year of cultivation of grassland but rises markedly in the second year.

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RECENT ADVANCES IN SUGAR-CANE CULTURE IN QUEENSLAND

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WITH PLATE I

Introduction

Climate.—The Queensland sugar industry is concentrated in four main areas within a narrow coastal belt and extends approximately from 16° to 28° south latitude. There is rather a wide variation in climatic conditions over this 1,000-mile strip of country, particularly with regard to temperature. All areas are influenced by late-summer monsoonal rains, the annual precipitation ranging from 40 in. in the south to 180 in. in the wet northern areas. The incidence of low rainfall in the spring and late winter is particularly favourable for harvesting operations and is also conducive to the ripening of the cane during this important period. The data from three districts in the very wet zone [1] have shown that a significant negative correlation ($P = 0{\cdot}05$) exists between the rain falling in the early part of the harvest season (June–August) and the sugar-content of the cane. The regression coefficients indicate that the decrease in C.C.S. (commercial cane sugar) is of the order 0·05, 0·11, and 0·09 units per inch of rainfall respectively in the three mill areas examined. Although serious droughts do occur, in most seasons the rainfall is sufficiently reliable and the bulk of the cane is grown under non-irrigated conditions; a contributing factor to the reluctance to install irrigation facilities is the widespread use of hardy canes which, although containing a proportion of wild blood, have good sugar qualities. An exception is in the Burdekin Delta where some 900,000 tons of cane are grown annually under irrigation. Water is readily available in this area from shallow underground supplies, and the increased returns are reflected in the yield figures, e.g. in 1948 the yield per acre amounted to 5·14 t. of sugar as compared with 3·01 t. for the whole of Queensland.

Labour.—An interesting fact is that although only about one-fifth of the cane is grown south of the Tropic of Capricorn all farm labour including that of cane-cutting is performed by workers of British or European descent. A further dissimilarity between Queensland and most other sugar industries is the individual ownership of relatively small farms, as compared with the large company-owned plantation system. Some 7,500 growers are engaged and the average area harvested is approximately 35 acres per farm.

Implements.—These farms are highly mechanized and most farm operations are carried out by tractor-drawn equipment. Cane harvesters and loaders are relatively little used, one of the main factors precluding the use of such machinery being its high capital cost in relation to individual farm output. However, of late years several small but efficient harvesters have been devised and it seems likely that the use of these

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will increase considerably in the future. Of particular interest is a shear-blade type of cutter which may be drawn by a light tractor. These machines merely sever the cane at the base and cause it to fall at right angles to the row where it is subsequently topped by hand. The latter operation is readily carried out manually, whereas it is particularly difficult to do it satisfactorily by mechanical means.

The use of the planting-machine is now normal practice in all areas. The type known as the cutter-planter is an efficient and labour-saving device. On land which has been prepared for planting, this machine will open the furrow, place the sett in the desired position, and finally cover it over with soil after applying the required fertilizer. The machine is fitted with a cutting mechanism that cuts the cane-stalk into three-bud seed pieces as it is fed into the delivery chute. An added advantage of the use of these planters is that the furrow is opened and the sett placed and covered in a matter of seconds. Previous methods requiring preliminary drilling-out of the field often resulted in the exposure of the soil in the open furrow for several hours, so that a considerable loss of soil moisture occurred which was reflected in lower germination and strike.

Cane-breeding and Varietal Work

Perhaps no other avenue of research has been more profitable than that of cane-breeding. New varieties have completely changed the production picture in many of the sugar areas. Although this work began in Queensland about 30 years ago, progress was of necessity very slow for some time. Possibly one of the main deterrents to quick results was the scarcity of suitable parent canes. However, as time went on the number of synthesized parents carrying many blood-line variants increased considerably and a wide range of new combinations became available. Thanks to their desirable agricultural characteristics, e.g. satisfactory stooling, vigour, ratooning ability, and disease resistance, such wild canes as *Saccharum spontaneum*, *S. berberi*, and *S. robustum* have been used extensively for crossing with the noble varieties (*S. officinarum*) in order to produce both commercial and parent canes. Particular attention has been given to the use of *S. robustum* since its natural habitat in New Guinea is climatically similar to the North Queensland sugar areas.

Success had been obtained by the importation of nobilized 'spontaneums' from India and Java. Although some of these Co. and P.O.J. canes have become useful commercial varieties in Queensland, their progeny has been much more successful. For instance, the crossing of P.O.J.2725 and Co.290 produced Q50. This seedling, which was first distributed in the Central Area in 1946, achieved immediate success and by 1949 nearly 50,000 acres had been planted. Another Coimbatore cane, Co.270, was unsuitable as a commercial cane in Queensland, but when crossed with 27M.Q1124 at the Colonial Sugar Refining Company's nursery in North Queensland gave rise to Trojan. This variety with its percentage of wild blood is capable of competing successfully with Badila on 'Badila land' and will outyield it in less fertile country. Since its initial propagation in 1933 Trojan made rapid progress until it

finally displaced Badila as Queenland's major variety. Two very useful canes that have done well in southern Queensland are Q47 and Q49, from the cross Co.290 × P.O.J.2878, giving further proof of the parental value of these imported canes. An interesting fact is that 32–8560, which was for many years the most important variety in Hawaii, is a Co.213 × P.O.J.2878 cross.

Although as previously mentioned *S. robustum* has been persisted with as a parent cane and many thousands of its progeny have been tested in various combinations, no useful commercial canes have yet been obtained [2]. Of these 'robustums' 28NG251, when nobilized by Badila, has yielded the most promising material. Further nobilization with Korpi is providing seedlings with desirable agricultural characteristics, although their disease resistance has not yet been determined.

For several years much emphasis has been placed upon the necessity to produce early maturing canes or canes with high sugar-content early in the season. The desirability of growing such canes is closely related to the economic length of the crushing season (normally June–December), which in turn is dictated by many factors, such as mill capacities, climatic conditions, labour, and other social requirements. In general most of the present varieties do not reach their highest sugar-content until about September–October. Cane harvested before this period is unripe, and obviously the harvesting of immature cane results in a considerable loss of sugar. For the reasons outlined it is not possible to confine the crushing to the period of maturity and therefore much effort has been directed to have available for early harvest canes that will ripen at the beginning of the season. Up to the present, efforts towards this end have not been attended with much success. Undoubtedly one of the major drawbacks has been the necessity to incorporate a certain proportion of wild blood in order to attain the required agricultural characteristics. It has been found that although the added wild blood conferred the desired vigour it also usually induced late maturity. Very few of the crosses obtained began to show promise commercially until the wild blood had been diluted to one-eighth or less. However, persistent efforts have recently proved successful and crosses have been obtained that are early maturers although they contain one-quarter wild blood [3]. The crossing of Korpi and Q13 with the 'half-robustums' C278 and C279 has been particularly valuable in this respect. Whether the progeny at present under trial will become commercial canes has yet to be determined, but it is satisfactory that wild-blooded early-maturing varieties are now available for crossing with early-maturing noble canes.

The introduction of F_1 and F_2 hybrids of the Turkmenistan cold-resistant 'spontaneum' has been made for the express purpose of breeding canes for the colder areas of southern Queensland. Some difficulty has been encountered because of the very early arrowing of these hybrids. However, crosses were eventually obtained with P.O.J.2725, producing seedlings which, although not of commercial type, were valuable as parent canes. The crossing of these with such canes as C.P.29/116, Comus, Eros, P.O.J.2875, P.O.J.2878, Trojan, &c., is providing progeny of considerable promise for the southern areas.

Hughes has pointed out [2] that the persistence of purely noble canes has been more marked in Queensland than in other sugar countries. This has been brought about to a large extent by the excellent yields given by the noble Badila. However, since this variety is best suited to tropical conditions and the more fertile soils of good moisture-holding capacity, the hardier and more vigorous wild-blooded crosses have tended gradually to replace it. This was particularly the case on marginal soils and in the colder areas. A contributing factor was their higher

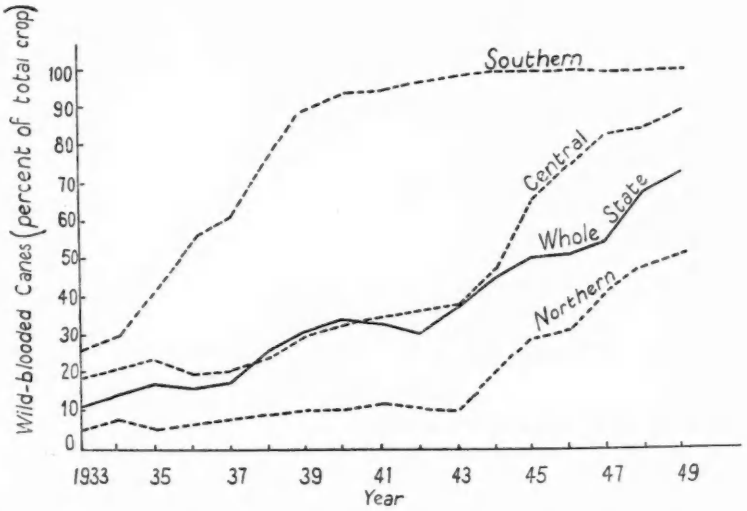

FIG. 1. Showing the increasing usage of canes containing wild blood over the years 1933–49. The curves show the amount harvested as a percentage of the total crop, for the Southern, Central, and Northern Districts, and also for the whole State.

degree of resistance to the ravages of the 'Greyback' grub, *Dermolepida albohirtum* (Waterh.), especially in the northern districts. However, some considerable time was to elapse before the newer seedlings showed any marked tendency to become commercial canes on what is popularly known as Badila country. Nevertheless, such a varietal revolution ultimately occurred and in the relatively short period of 16 years the percentage of noble canes harvested in Queensland dropped from approximately 90 to less than 30. The general trend of these changes is shown in Fig. 1, from which it will be seen that the change is practically complete in the southern districts and is also very well marked in the central areas. In northern Queensland, however, due mainly to the predominance of Badila, an almost even balance is maintained at the present time between the purely noble canes and varieties containing a proportion of wild blood.

Soil Fertility Investigation

Mineral deficiencies.—A myth that has long since been exploded in Queensland is the reputed high degree of natural fertility of tropical soils. It is indeed a fact that the great majority of the sugar-growing soils in both the tropical and sub-tropical districts are highly leached and acidic in nature. There is evidence of strong podsolization and the low base-status of both surface and subsoil horizons is characteristic. Under eucalypt forest there is no A_0 horizon and that which develops under rain forest quickly loses a great deal of its organic matter with cultivation. The rate of loss of organic residues when incorporated with the

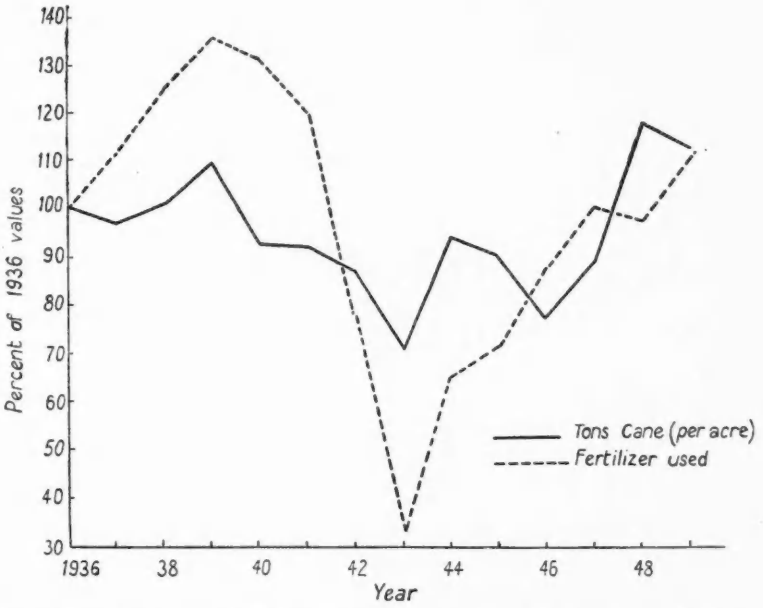

FIG. 2. Relation of yield (tons cane per acre) to the total fertilizer used by the sugar industry (1936–49). N.B. The yields for 1946–7 were affected by severe drought.

soil is appreciable and is well illustrated by the results of a trial which has been running for some 15 years on the Sugar Experiment Station in southern Queensland. This trial was designed to compare the results obtained by ploughing-under all the trash and tops of the crops harvested with those in which such plant-residues have been completely removed from the field. Although some 220 t. of green matter from the 9 crops harvested to date have been returned to the soil in this way, repeated analyses have failed to detect any increase in the organic-carbon content of the soil.

As might be expected, therefore, a considerable response is obtained

from the application of nitrogen, phosphoric acid, and potash, and complete fertilization is universally practised in most districts. The necessity for such a procedure is indicated by comparing the mean seasonal yields in tons of cane per acre with the total fertilizer used throughout the industry during the previous year. The enforced decrease in fertilizer usage from 61,000 to 15,000 t. as a result of war-time shortages brought about a marked decline in production, as shown by the general trends illustrated in Fig. 2 (page 17).

Because the dependence upon the application of fertilizer in order to attain maximum production has long been recognized, a considerable amount of research work has been devoted to the problem of defining both qualitative and quantitative requirements. The correlation of data from laboratory and field work by Kerr and von Stieglitz [4] has resulted in the adoption of chemical methods by means of which the phosphate and potash requirements of the many soil types could be very satisfactorily estimated. Available phosphate is determined by leaching the soil with N/100 sulphuric acid under standardized conditions. Exchangeable potassium is used as a measure of potash availability, the potash being expressed as the percentage of total exchangeable base present in the soil. From these studies very useful data have emerged for defining fertility gradients as far as phosphate and potash are concerned. The tables compiled by von Stieglitz [5] are reproduced below:

Available phosphate:

Very low: All soils with $<$ 20 p.p.m. P_2O_5.
Low: 20–40 p.p.m. P_2O_5.
Medium: 41–60 p.p.m. P_2O_5.
High: $>$ 60 p.p.m. P_2O_5.

Available potash:

Very low: All soils with less than 0·10 m.e. exchangeable K per 100 gm.
Low: 0·10–0·12 m.e. exchangeable K per 100 gm. or exchangeable K less than 2 per cent. of the total exchangeable bases present.
Medium: 0·12–0·18 m.e. exchangeable K and when this exchangeable K is also greater than 2 per cent. of the total exchangeable bases present.
High: $>$ 0·18 m.e. exchangeable K and when this exchangeable K is also greater than 2 per cent. of the total exchangeable bases present.

The above values have now been used for many years as a basis for the routine advisory work carried out by this Bureau in which many thousands of soil samples have been analysed for growers. In addition to the testing of soils for individual farmers, a policy of carrying out fertility surveys in selected areas representing major soil types was instituted in 1940 and has remained a regular and valuable feature of extension work since that date. Field officers systematically sample plant-cane blocks in the areas concerned, and by this means the possibility of changes in fertilizer requirement occurring with continued cultivation is not overlooked. It is noteworthy that whereas phosphate was once regarded as the major mineral plant-nutrient deficiency, there are now indications that potash requirement is becoming much more marked [6].

This is possibly a reflection of the use of high phosphatic fertilizers over the years. In each of the survey areas a $3 \times 3 \times 3$ factorial fertilizer trial with three levels of NPK is laid down in order to define as closely as possible the required quantities of each of these three essential materials.

An indication of the importance to the industry of correct and economic fertilizer usage is the attitude of several of the co-operative (farmer-owned) sugar-milling companies. Each of these mills employs several qualified chemists for the purpose of factory control, and also because each farmer is paid according to the sugar-content of his cane. In the slack season these chemists may be employed on soil analytical work in close co-operation with the Bureau of Sugar Experiment Stations. In this way not only is the acreage embraced by fertility surveys increased but continuity of employment is ensured for essential technical mill personnel.

With the exception of copper, no minor-element soil deficiencies have yet been observed. In recent years limited outbreaks of 'droopy top disease' have occurred in both the southern and central areas, mainly on light-textured and rather infertile soils. The symptoms, which have been described by Steindl [7], are characterized by a slow unfurling of the young leaves and the formation of a long, tightly rolled spindle which, together with the rest of the top, assumes a drooping position. Chlorotic stripes between the major vascular bundles occur on the leaves, stools may be considerably stunted, and death often ensues. It has been found that this disorder responds favourably to soil applications of 56 lb. of copper sulphate per acre, and when this is applied before planting complete control can be effected.

Soil deterioration.—Sugar-cane growing has been a prominent industry in Queensland for over 50 years. The area under cane in 1895 was approximately 70,000 acres, and this had increased to over 100,000 by the beginning of the present century. By 1922 the acreage had been doubled and with further increases 300,000 acres were under cane in 1931. Ten years later the acreage had increased to approximately 350,000, since when there has been no further change. Under the assignment system, which was instituted in 1915–16 to restrict production within marketable limits, the growing of cane for milling on land other than that assigned by law is forbidden. By about 1931 most of the assigned land was cultivated and producing cane. At the present time about one-third of this land has been growing cane for over 50 years, whilst about one-half has been doing so for approximately 30 years.

In addition to the restriction imposed by the assignment system the necessity to maintain continuous production on these already developed areas is further emphasized by the centralization demanded by such economic considerations as capital outlays on milling plants and transport facilities. However, since a farmer is not allowed to harvest more than 75 per cent. of his gross assigned area in any year, the soil undergoes a 9 to 12 months' fallow period every 3 to 4 years.

For many reasons, mainly economic, there is at the present time no alternative crop that could be grown in rotation with cane in the greater part of the sugar area. Although many Queensland cane soils have now

been cultivated for some 50 years, this period is relatively short in comparison with conditions occurring in overseas sugar areas. Nevertheless, the fact that the industry is being maintained on a one-crop basis, and apparently must continue to do so, has occasioned serious thought. The question whether these soils are deteriorating and are becoming less productive is difficult to answer. There is no gainsaying the fact that their yields are increasing and the amount of sugar produced per acre during recent years is higher than ever. Queensland's estimated production this year (1950) is over 7 m. t. of cane—an all-time record—without any significant increase in acreage harvested. There is no definite evidence to suggest that increased difficulty is being encountered in growing the crop, nor is production less reliable. Arguments have been raised suggesting that in the light of better varieties, modern cultivation methods, satisfactory disease control, and more efficient usage of fertilizer, the improvement in production should be greater. It has been inferred that there is a concomitant decline in soil fertility that tends to offset the benefits produced by agricultural research. From a consideration of Hawaiian conditions, Baver [8] has suggested that since 1930 the planting of improved varieties should have increased yields in that country by about 20 per cent., whereas a 9 per cent. increase only was achieved. In Queensland, however, it is difficult to find such a discrepancy between theoretical yields of the newer varieties as based upon their performance in testing-trials and their behaviour once they become established as commercial canes. Indeed, it is unlikely that differences approaching the above-mentioned magnitude exist.

Undoubtedly there are many factors that control the maintenance of soil fertility. They may be briefly summarized as: (*a*) the loss of soil by erosion, (*b*) accumulation of disease organisms and pests in the soil, (*c*) inability to control weeds, (*d*) loss of plant nutrients, and (*e*) maintenance of a favourable physical and biological condition in the soil. These have been studied in some detail for Queensland cane soils [9]. It would seem that, whilst it would definitely be unwise to view them too complacently, the first four of these do not appear to be limiting production under the present methods existing in the majority of the sugar districts.

In regard to the maintenance of physical condition, many workers have shown that soil micro-organisms exert a profound influence upon soil structure. The recent researches of Swaby [10] have emphasized the beneficial effect of fungal hyphae on the formation of water-stable aggregates, and the value of substances of high sugar-content in promoting the development of soil fungi. Organic residues with a narrow C/N ratio are also valuable in this respect. There is ample evidence in Queensland to indicate the beneficial effect of applications of molasses to the soil. In all mill areas there is a great demand for this by-product, which contains approximately 40 per cent. of total sugars, and the acreage to which it is applied is limited only by the amount available. The increases in crop yields cannot always be explained merely by the amount of plant-food present in the molasses. In many instances there is a distinct visible improvement in the physical condition of the soil. During

the past two years the Bureau laboratories have devoted much time to the measurement of the effect of molasses on soil structure. It is evident that applications of this material bring about a large increase in the percentage of water-stable aggregates greater than 1·0 mm. and 0·5 mm. diameter [11]. In Plate 1, *a* and *b* show the effect of an application of molasses at the rate of 12 t. per acre under laboratory conditions to a red volcanic soil from southern Queensland, and the similar but very much smaller aggregates in the same quantity of untreated soil. Recent work by this laboratory [12] has indicated that not only the application of molasses but also the turning-in of residues of high-sugar-yielding crops such as sweet sorghums has a beneficial effect on soil structure. These studies have shown that a 35-t. crop of sweet sorghum, which was cut up and dug into a clay loam soil, increased the content of water-stable aggregates $> 0{\cdot}5$ mm. diameter from 11 to 39 per cent., whilst the fraction $> 1{\cdot}0$ mm. was increased from 6 to 35 per cent. This change occurred over a period of 90 days.

In view of the difficulty in finding clear-cut evidence that the physical condition of sugar-cane soils deteriorates significantly under continuous cultivation, the possibility that this crop is one which assists the soil to maintain a favourable structural state should not be ignored. It is not unlikely that the appreciable sugar-content of stubble and stalk residues is important in this respect, since it encourages the development of soil microflora. For the same reason the application of molasses is undoubtedly of value as is also the present almost universal practice of growing a leguminous green-manure crop between the ploughing-out of the final ratoon crop and replanting.

The Use of Benzene Hexachloride

Control of the 'Greyback' grub.—The larvae of various Scarabaeid beetles are capable of damaging the roots of the cane-plant, and that of the 'greyback' cockchafer, *Dermolepida albohirtum* (Waterh.), is particularly destructive in this respect. In certain years it has been responsible for enormous losses; for instance, it has been estimated that in 1946 approximately 105,000 t. of cane were lost in the Tully-Cairns area alone. Records, which have been kept since 1934, indicate that such depredations are not isolated cases and that in most years appreciable losses occur. Areas of highly productive soils have gone out of production because of the absence of effective and economical control measures.

However, recent work that was begun in 1946 by Mungomery [13] and his co-workers has shown that correct application of benzene hexachloride dust will provide sure and effective protection against grub damage on even the most highly infested areas. The use of this insecticide has made rapid strides during the past two years, and from the small amount available in the initial period the demand has been so great that in 1949 some 900 t. were applied to approximately 20,000 acres. The value of the treatment is being spectacularly demonstrated in the crops to be harvested this season (1950) in North Queensland, since there is ample evidence that the tonnages on soils known to be highly susceptible to grub attack are appreciably greater than those areas where the

previous history seemed to indicate that the incidence of infestation was sufficiently low not to warrant the application of benzene hexachloride. These differences are revealing unsuspected losses on areas previously considered safe, and it is reasonable to assume that even greater acreages will be treated in future. An interesting point is the possible effect on the noble cane Badila. As previously mentioned, one of the reasons for the reduced plantings of this excellent sugar producer was the greater resistance to grub attack of the more vigorously rooting wild-blooded canes. It may well be that the relatively inexpensive control of the grub pest provided by benzene hexachloride will lead to Badila regaining pride of place as Queensland's major variety.

Of considerable importance is the fact that an application of benzene hexachloride to the plant-crop will also confer immunity upon the subsequent first and second ratoons. There is evidently a quantitative relationship between the amount applied and the duration of the period for which the application remains sufficiently toxic, since a dressing of 150 lb. per acre of 10 per cent. dust is required to protect the three crops. Where protection is required for two crops only, an application of 125 lb. per acre has been found to be sufficient, whilst 100 lb. is adequate for one crop. Up to the present the dust normally used contains 10 per cent. benzene hexachloride (1·3 per cent. gamma isomer) in which the diluent is either pyrophyllite or a mixture of pyrophyllite and finely ground rock phosphate. The mixed diluent has been found to be more satisfactory than either of these two materials used singly. In addition the fertilizer value of the phosphate rock is appreciable. Recent tests indicate that a more concentrated dust containing 2·6 per cent. gamma isomer can be satisfactorily handled with a consequent saving in transport costs. Research work [13] has shown the necessity for fairly close adherence to the recommended method as far as placement and time of application are concerned. Owing to the known residual insecticidal effect the possibility of a build-up in the soil to phytotoxic proportions has also been studied in some detail. However, it seems most unlikely that normal field applications will be accompanied by any adverse effects. With the rapid rise to popularity of this insecticide many new types of tractor-drawn distributors have been developed [14], whilst existing fertilizer distributors have also been satisfactorily modified [15]. Some of these units are capable of treating over 20 acres per day.

Frenchi grub control.—The two-year cycle Scarabaeid (*Lepidiota frenchi* Blkb.) has proved much more difficult to control with benzene hexachloride than the one-year cycle 'greyback'. Although the larvae of frenchi is also very susceptible to this insecticide, the habit of the grub to descend into the subsoil below plough-depth in order to undergo a resting period before assuming the third stage somewhat complicates the position. The erratic return of the third-stage grub (which is the destructive stage) to the root-zone together with patchy infestation has made the task of defining economic rates of application difficult. The habits of both beetle and larvae have been studied in detail, and it is well known that when infestation occurs in one crop the damage occurs

when the grub in the third stage moves upward from the subsoil to attack the roots of the subsequent crop. In a recent experiment infestation was observed in the plant-crop, and the succeeding first ratoon was completely protected by an application of 150 lb. of benzene hexachloride per acre. Damage was so great in the untreated control plots that practically no harvestable cane was present. In some cases frenchi infestation occurs in the first ratoon with resultant damage to the second ratoon crop. It appears that further experimental work is necessary to define an economic procedure for the control of this grub. Fortunately, although it may cause appreciable losses in certain areas, this pest is of much less importance than *D. albohirtum*.

Wireworm control.—For many years wireworms (*Lacon variablis* Cand.) have caused appreciable damage in the lower-lying areas of the Mackay and Proserpine districts. The destruction of many of the buds of newly planted cane-setts often necessitated the planting of infested areas several times before a satisfactory germination rate was obtained. Costly drainage measures were necessary to reduce the incidence of the pest, and whilst the provision of good drainage is desirable agriculturally, the requirement in respect of wireworm control was frequently much greater than was necessary to produce satisfactory cane crops. Preliminary experiments indicated the potential value of benzene hexachloride and a commercial control of *L. variablis* was quickly evolved. At the present time little or no loss occurs on even the most susceptible wireworm country. Complete protection is afforded by an application of 20 lb. of benzene hexachloride (1·3 per cent. gamma isomer) per acre. This may be conveniently mixed with the fertilizer normally applied in the drill at planting, and such mixtures are in commercial supply. Some adjustment to the chutes of the fertilizer distributor is necessary since damage to young roots has been recorded where benzene hexachloride has come into direct contact with the germinating sett. This, however, may be readily avoided by suitable placement of the insecticide.

Disease Control

As an inheritance from its policy of importing new varieties from many overseas countries in the early stages of its history before the existence of adequate quarantine facilities, Queensland acquired almost every sugar-cane disease of economic importance. Several of these, such as Fiji disease, Gumming disease (*Bacterium vasculorum* (Cobb) Grieg-Smith), and Downy Mildew (*Sclerospora sacchari* T. Miy), are capable of causing enormous losses, and in the past very serious outbreaks have occurred. Other diseases such as Leaf Scald (*Xanthomonas albilineans* Ashby), Mosaic, Red Rot (*Physalospora tucumanensis*), and Chlorotic Streak are of importance. However, notwithstanding the potential threat of these many diseases, the direct losses caused by them of recent years are not great. Such a satisfactory state of affairs is directly attributable to the seriousness with which the industry regards the position, and its insistence on the strict imposition of legislative measures designed to control plantings and in certain cases immediately to destroy any diseased canes. These measures are implemented under the Sugar

Experiment Stations Acts, 1900 to 1948, which provide the authority for prohibiting the planting of any variety not gazetted as an 'approved variety'. By this means the planting of resistant or tolerant varieties can be enforced in disease-infested areas. Of course, it is not always possible to substitute non- or less-susceptible canes which have equally desirable yield and agricultural characteristics. Therefore a system of extensive roguing is often necessary to remove potential sources of the spread of the disease. Such work is carried out by the field inspectors of the various Cane Pest and Disease Control Boards which have been established throughout the sugar districts. Some 21 Boards are in existence, the powers of which are derived from the above-mentioned Acts. In addition the State has been divided into ten permanent quarantine districts and the removal of cane from one to the other is prohibited unless by special permit; this also applies to subsidiary quarantine areas which may be imposed from time to time to further localize any disease outbreak. There is no doubt that this control of disease based on legislature has produced excellent results.

Possibly the only disease that has been controlled by fungicidal or other direct treatment is 'pineapple' disease (*Ceratostomella paradoxa*). Some areas, particularly in late autumn or winter plantings, suffer from poor germination due to the invasion of the planted sett by this fungus. In cold soils that are sufficiently moist, the inroad of the organism through the cut ends of the seed-piece is more rapid than the retarded germination of the bud. The result is that the bud fails to develop and a very poor strike is obtained, necessitating a considerable amount of replanting. Experimental work indicated that complete protection could be afforded to the sett by using organic mercurial compounds. This was rapidly followed by commercial application, and many efficient and economic dipping units are in use, some of which will dip a ton of cane in one operation. The solution used contains 0·015 per cent. mercury, and a half-minute dip will suffice [16]. A practical difficulty that has occurred is in connexion with the use of the cutter-planter. Since this very popular planting-machine cuts the stalk into setts prior to placing the seed-cane in the furrow, it is not possible to dip the setts before planting with such equipment. Therefore the grower has had to revert to the older type of drop planter in which the setts are cut beforehand. A typical example of the advantage of mercurial dipping is well illustrated in Plate 1 *c*.

Acknowledgements

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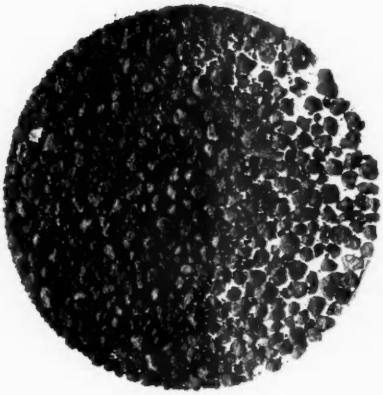

a. Showing the formation of water-stable aggregates in a red loam due to the application of molasses

b. A sample of the same red loam that had not been treated with molasses

c. A field of plant-cane in the Burdekin district. The better germination in the rows on the right is due to dipping the setts in a mercurial solution before planting

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THE CONTROL OF WEEDS IN MAIZE WITH SELECTIVE PLANT-GROWTH REGULATORS

SECOND REPORT 1949–50 SEASON

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THE experiments conducted during the 1948–9 season and reported by Altona [1] were followed up in the 1949–50 season by a further series of experiments, which although still fundamental, had a more practical bias and included cultivation treatments. As the results of the 1948–9 season showed no significant difference between Methoxone and DCPA, the former weedkiller was discarded in 1949–50.

Experiments were laid down in two different areas: at Frankenwald, the Botanical Field Station of the University of the Witwatersrand, in the Johannesburg district, Transvaal, and on a farm in the Bethlehem district, Orange Free State. The experiments in each area will be presented separately.

Frankenwald

Materials and methods.—The sodium salt of DCPA, at the rate of 1 lb. of the active principle (0·85 lb. acid equivalent) per acre, was used throughout. The herbicide was diluted with water and applied with a knapsack sprayer at a volume rate of 50–60 gallons of total solution per acre, unless otherwise stated. Prior to the last cultivation before planting, 200 lb. per acre of Mixture E fertilizer (4–12–0) was broadcast over the experimental area. Spacing was 3 × 3 ft. with 3 kernels per hill planted by hand. After germination the maize plants were thinned out to one plant per hill. The variety of maize planted was Anveld. Plot size was 12 × 12 sq. yds. of which 11 × 11 sq. yds. (1/40th acre) was harvested. All treatments were replicated four times in a randomized block system. Cultivation was carried out by hand-hoeing, so that after treatment the plots were perfectly clean. Planting took place on 2.12.49 and the cobs were harvested on 4.5.50. The soil, derived from old granite, is sandy and low in nutrients with a pH of 5·8. Treatments were as follows:

1. DCPA: 5 days after planting. No cultivation.
2. ,, 5 days after planting plus one cultivation.
3. ,, 5 days after planting plus two cultivations.
4. ,, Kept clean by cultivation.
5. ,, No cultivation.
6. ,, 5 days after planting. Concentration 0·1 per cent. No cultivation.
7. ,, 5 days after planting. Concentration 0·25 per cent. No cultivation.

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8. DCPA: 5 days after planting. Concentration 0·5 per cent. No cultivation.
9. „ 3 weeks after emergence along the rows. No cultivation.
10. „ 3 weeks after emergence between the rows. No cultivation.

In Treatment 2 the cultivation was carried out when a sufficient number of weeds had made their appearance to warrant a cultivation. This took place on 13.1.50. Treatment 3 received its first cultivation on 13.1.50 and its second on 22.2.50. Treatment 4 was cultivated on 28.12.49, 23.1.50, 13.2.50, and 14.3.50. These four cultivations were sufficient to keep the plots clean. In Treatments 6, 7, and 8 the concentration of solution applied varied in an attempt to see if the concentration affected the young maize seedlings in any way. As all the DCPA treatments were pre-emergence, which was found in the 1948–9 season to be the most suitable time of application for the control of annual grasses and sedges, Treatments 9 and 10 were included to see what the effect would be when young maize plants were sprayed. The rainfall for the growing-season is given in Table 1.

TABLE 1. *Rainfall 1949–50*

	Oct.	*Nov.*	*Dec.*	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*Total*
Inches . .	2·32	9·35	9·85	2·53	2·96	3·18	2·04	32·23

Results and Discussion

TABLE 2. *Weights of the Harvested Grain from the Various Treatments with DCPA*

Treatment	*Mean yields of grain*	
	Per plot in lb.	*In 200 lb. bags per morgen**
1. No cultivations	16·72	7·05
2. One cultivation	32·62	13·75
3. Two cultivations	33·25	14·03
4. Cultivation	31·56	13·32
5. No cultivations	8·88	3·74
6. DCPA 0·1 per cent., no cultivation .	18·29	7·30
7. DCPA 0·25 per cent., no cultivations	16·70	7·04
8. DCPA 0·5 per cent., no cultivations.	17·5	7·24
9. Sprayed with DCPA along rows, maize 6 in. high	15·27	6·44
10. Do. between rows, maize 6 in. high.	14·60	6·16
Significant difference at 5 per cent. level.	7·49	3·16

* 1 morgen = 10,244 sq. yds. (Eng.) = 2·116 acres.

The principal weeds encountered were the annual grass, *Eleusine indica* (Goose grass, Jong Os Gras, or Sterkpol), and the sedge, *Cyperus esculentus* (Water grass or Uintjie). Dicotyledonous plants were infrequent. In the 'no herbicide no cultivation' plots the surface of the ground

was covered by a thick mat of the annual grass and sedge by the end of January. The results indicate that the DCPA plus cultivation is significantly better than DCPA without any cultivation. The DCPA with one early cultivation treatment produced as good a yield as the DCPA plus two cultivations and as good a yield as the untreated, 'clean-cultivation' treatment. This supports the findings of Hogue and Rothgeb [2] in the U.S.A., who found that plots treated with DCPA and one cultivation did not differ significantly from the all-cultivation plots. At the same time, it must be remembered that the season was wet in the beginning, producing luxuriant weed-growth, but later in the season, conditions being drier, were not nearly so favourable for weed-growth. Had the rainfall been more evenly distributed the results might not have favoured the herbicide plus one cultivation to such an extent. However, the results do bring out the important point in maize production that early control of weeds is essential, weed eradication later in the season not being so important.

Concentration of solution applied does not appear to affect the final yield. This is of interest when choosing the type of sprayer to be used in farming-practice. Three weeks after emergence the maize plants (Treatments 9 and 10) had reached a height of 6 in. when sprayed. At this height Anveld maize does not appear to suffer any damage visually or by final weight-yield. In the U.S.A. workers are still at variance as to the height at which the maize plant is least susceptible to damage. Buchholtz [3] reports that it suffers greatest injury when treated between 10 and 40 in. high. Others, Bakke and Sylvester [4] and Lee [5], recommend spraying the plants at heights varying from 12 to 16 in., whilst Murray and Whiting [6] noted spray injury of the leaves when treating maize plants 9 in. high. Most of these experiments were carried out on 'sweet corn', inbred lines, and hybrid maize. Rossman and Staniforth [7] reported that inbred lines of corn may differ in their response to DCPA, a finding that also seems to apply to hybrid maize. The co-ordinating committee of the Northeastern States Weed Control Conference for 1950 (U.S.A.) [8] recommended that more work should be done on the response of different hybrids to DCPA.

No conclusions can be drawn here as to the susceptibility to DCPA of the many varieties of maize grown in South Africa except that the results, over two seasons, indicate that Anveld maize is resistant to both pre-emergence spray and post-emergence foliar spray. Hybrid maize may be less tolerant, but as next season will be the first time in South Africa that seed in small quantities will be made available to the farmers, the answer will not be required in practice for another few seasons.

Bethlehem

Materials and methods.—The sodium salt, the triethanolamine salt, and the ethyl ester were used in this experiment as pre-emergence sprays. The rate of application for all three was 1 lb. acid equivalent per acre. A knapsack sprayer fitted with special jets was used so that the volume-rate applied was 6 to 7 gals. solution per acre in one series and a higher volume of 20 to 22 gals. solution per acre in another series of

treatments. No fertilizer was applied to the experimental area. The variety of maize planted was Anveld, with spacing 3 ft. × 18 in. The seed was planted by hand, four kernels per hill, with thinning out at a later date to one kernel per hill. The size of each plot was 6 × 23 sq. yds. of which 5 × 20 sq. yds. (1/48th acre) was harvested. Treatments were replicated four times in randomized blocks. The soil is of a sandy nature derived from the Cave Sandstone Beds. Planting took place on 7.11.49, and the treated plots were sprayed on 15.11.49. Treatments were as follows:

1. Sodium salt, no cultivations.
2. Ethyl ester, no cultivations.
3. Amine salt, no cultivations.
4. Untreated, no cultivations.
5. Sodium salt plus one cultivation.
6. Ethyl ester plus one cultivation.
7. Amine salt plus one cultivation.
8. Untreated plus one cultivation.
9. Sodium salt plus three cultivations.
10. Ethyl ester plus three cultivations.
11. Amine salt plus three cultivations.
12. Untreated plus three cultivations.

The volume-rate in the above treatments was 6 to 7 gals. per acre.

13. Sodium salt plus one cultivation.
14. Ethyl ester plus one cultivation.
15. Amine salt plus one cultivation.
16. Control. Kept clean by cultivation.

The volume-rate in 13, 14, and 15 was 20 to 22 gals. per acre. In all treatments the rate of application was 1 lb. acid equivalent per acre.

In Treatment 16 the weeds were hoed out whenever they made their appearance. All other cultivation treatments were carried out by mechanical means, which meant that weeds growing between the maize plants were left undisturbed. The untreated plots were cultivated at the same time as the treated plots. The rainfall for the growing-season is given in Table 3.

TABLE 3. *Rainfall 1949–50*

	Nov.	*Dec.*	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*Total*
Inches . .	4·11	5·07	2·91	3·89	2·87	4·55	2·92	26·32

Results and discussion.—Owing to rain, spraying was delayed to the eighth day after planting. Just after the plots had been sprayed it began to rain and over the next 2 days 1·34 in. were recorded. This rain, no doubt, reduced the effectiveness of the herbicidal treatments and also spoiled any comparison that might have arisen between the two volume-rates applied. Owing to the wet condition of the land it was impossible

to carry out any mechanical cultivation before 23.12.49. In the control where cultivation was done by hand-hoeing, the plots were kept clean regardless of the weather. On 9.12.49, 24 days after spraying, weed-counts were made and each plot assessed over a range of 1 to 6 (Table 4) as to its state of weed infestation.

TABLE 4. *Mean Weed-Population of the Treated and Untreated Plots*

Treatment	*Mean weed-population*
Sodium salt . .	2·0
Ethyl ester . .	1·58
Amine salt . .	1·08
Untreated . .	5·9

1. Very clean.
2. Clean.
3. Fairly clean.
4. Fairly dirty.
5. Dirty.
6. Very dirty.

The principal weeds were annual grasses, Khakibos (*Tagetes minuta*) and some Steenboksuring (*Rumex acetocella*).

In spite of the rain which fell just after the herbicides were applied, good weed control was obtained in all the treated plots for over a month after planting. Weed infestation in the untreated plots was heavy. The ester caused leaf-curl in the young maize plants, but no toxic effects were noticed where the amine and sodium salts were used.

The maize plants in the untreated plots never recovered from this early weed competition, and even where they subsequently received three cultivations their growth was stunted, and during the latter part of the season, when conditions were drier, the plants wilted badly.

TABLE 5. *Weights of the Harvested Grain from Treatments with DCPA*

Treatment	*Mean yield of grain*	
	Per plot in lb.	*200 lb. bags per morgen*
1. Sodium salt, no cultivation . .	4·73	2·4
2. Ester, no cultivation . . .	4·39	2·2
3. Amine, no cultivation . . .	10·64	5·4
4. Untreated, no cultivation . .	0·45	0·2
5. Sodium salt, one cultivation . .	11·19	5·6
6. Ester, one cultivation . . .	13·95	7·0
7. Amine, one cultivation . . .	20·12	10·2
8. Untreated, one cultivation . .	3·50	1·7
9. Sodium salt, three cultivations .	16·79	8·5
10. Ester, three cultivations. . .	18·66	9·4
11. Amine, three cultivations . .	20·12	10·2
12. Untreated, three cultivations . .	7·86	4·0
13. Sodium salt, one cultivation . .	12·90	6·5
14. Ester, one cultivation . . .	12·79	6·4
15. Amine, one cultivation . .	20·53	10·4
16. Control, kept clean by cultivation .	27·31	13·8
Significant difference at 5 per cent. level .	4·44	2·24

In all treatments the rate of application of DCPA was 1 lb. acid equivalent per acre; in Nos. 1–12 the volume-rate was 6–7 gals. per acre, in Nos. 13, 14, 15, 20–22 gals. per acre.

The overall results indicate the following:

1. All three herbicides kept the weeds in check for at least a month after planting-time.

2. The amine salt was significantly better than either the ethyl ester or the sodium salt, but there was no significant difference between the two latter.

3. The ethyl ester caused leaf-roll in the young maize plants. The sodium and amine salts did not appear to harm the plants in any way.

4. Herbicide plus cultivations outyielded the 'herbicide only' treatments.

5. The untreated plots given the same number of cultivations as the treated plots yielded less than the treated plots.

6. Where the amine salt was used as a pre-emergence spray, three subsequent cultivations did not give a better crop than one cultivation, but in the case of the other two compounds there was an increase in yield.

7. There was no significant difference in effect between the two volume-rates. Immediate rain after spraying probably cancelled any difference that might have occurred.

The control gave the highest yield, but as it was the only treatment where cultivation was carried out between the maize plants as well as between the rows, this was to be expected. It must be stressed that the practice of cultivating between the rows only leaves undisturbed large weed populations in the rows between the maize plants.

Summary.—Experiments on weed control in maize lands were carried out in the Johannesburg district, Transvaal, and in the Bethlehem district, Orange Free State. In the Transvaal the sodium salt of DCPA was used as a pre-emergence spray, with and without cultivations. A clean-cultivation treatment acted as a control. The results showed that spraying plus one cultivation produced the same grain yield as the control. The yield of grain from spraying without cultivation was significantly lower than with cultivation. Maize plants sprayed at a height of 6 in. showed no signs of being affected by the herbicide. Solutions of different concentrations resulted in the same degree of weed control without affecting the maize plants.

In the Orange Free State the ethyl ester, sodium and amine salts of DCPA were applied as pre-emergence sprays with and without cultivations. The ester was the only compound to cause any damage to the young maize plants, and it took the form of leaf-roll. The three compounds effectively controlled weeds for over 3 weeks after application. The amine salt gave the best results, but there was no significant difference between the ester and sodium salt. Herbicide plus cultivations

was significantly better than herbicide alone. The amine salt plus three cultivations did not increase the yield of grain above that of the salt plus one cultivation, but in the case of the ester and sodium salt the yields were increased by the extra cultivations.

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FIELD EXPERIMENTS IN SELECTIVE WEED CONTROL BY PLANT-GROWTH REGULATORS

III. WEED CONTROL IN GRASSLAND

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Introduction.—The ultimate aim of good grazing management is to provide as nearly as possible a constant supply of leafy and nutritious herbage at all seasons of the year. In most climates it is necessary to make provision against later shortage by conserving surplus growth during the most productive season either by ensilage or by haymaking or by artificial drying. The quality of herbage plants is therefore judged not only by the chemical composition and digestibility of their foliage but by their ability to make leafy growth over a long period, particularly under conditions of drought. The less productive species may, for example, have a special value in providing fresh, green, and palatable material when none other is available. For this reason it is not always easy to say which types are desirable and which constitute weeds. Grasses such as bent (Agrostis spp.) and Yorkshire fog (*Holcus lanatus*) are troublesome on good land, yet play a useful part in moorland and mountain pastures. Strips of chicory (*Cichorium intybus*), yarrow (*Achillea millefolium*), burnet (*Sanguisorba officinalis*), and ribgrass (*Plantago lanceolata*) are deliberately sown across intensively-managed ryegrass pastures in order to provide a varied and balanced diet. Even daisies (*Bellis perennis*), dandelions (*Taraxacum officinale*), cat's-ear (*Hypochoeris radicata*), heath rush (*Juncus squarrosus*), and sedges (Carex spp.), which are normally regarded as weeds, are frequently relished by grazing stock and consumed in preference to grasses. These plants, in fact, are on the borderline between the useful and the unwanted; their numbers must be kept in check, yet it is not desirable that they should be entirely eliminated. Of the undesirability of other weeds such as thistles (Cirsium spp.) or ragwort (*Senecio jacobaea*), which are unpalatable or even poisonous, there can be no doubt.

The problem of weed control in grassland is thus more complex than in arable land and far more difficult to evaluate. According to Hamilton [1], weed control is not a serious problem under systems of good grassland management involving adequate drainage and the wise use of fertilizers and lime, but there can be no doubt that present output is limited on large areas of permanent pasture by severe weed infestation. On much of this land the remedy of ploughing-out and reseeding, if necessary after arable cropping, is unlikely to be practised. The use of synthetic growth-regulators as selective herbicides appears to offer a simple and attractive alternative.

Experimental Results

The field experiments at Jealott's Hill on weed control in cereal crops with the sodium salts of 4-chloro-2-methylphenoxyacetic acid (MCPA)

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and 2,4-dichlorophenoxyacetic acid (DCPA or 2,4-D), which the authors have described in previous papers [2, 3], were extended in the autumn of 1943 to include weed control in grassland. Apart from an early trial on nettles[1] and two experiments on thistle-infested pasture at Jealott's Hill Research Station, the investigations were carried out at centres specially selected for the predominance of one or other of the major grassland weeds: thistles, ragwort, buttercups, docks, and bracken.

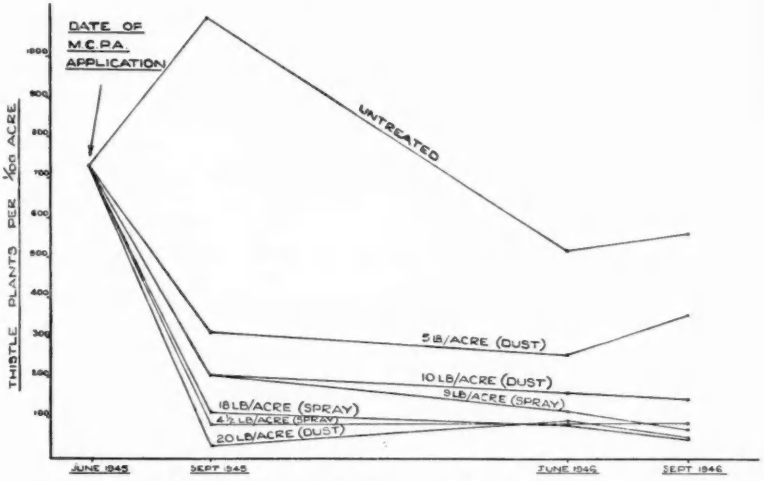

FIG. 1. Experiment CM1, Jealott's Hill, 1945–6. Control of creeping thistle (*Cirsium arvense*).

Much of this outside work was done in conjunction with co-operating farmers by members of the staff of Imperial Chemical Industries Limited, Central Agricultural Control (Development Department), to whom the authors make due acknowledgement. Our thanks are also due to Mr. D. Doxey, who assisted with the experiments at Jealott's Hill.

CREEPING THISTLE (*Cirsium arvense*)

1945–6 Experiment, Jealott's Hill. The first experiment, designed to compare the effects of MCPA at 5, 10, and 20 lb. per acre, in 2 cwt. dust or 100 gals. spray per acre, was begun in 1945 on a permanent grass sward infested with thistles and, to a less extent, with dandelion, yarrow, bulbous buttercup (*Ranunculus bulbosus*), cinquefoil (*Potentilla reptans*), and sorrel (Rumex sp.). The treatments were applied on June 12 when the thistles were just beginning to flower. Owing to an error the spray solution was made up to a concentration 10 per cent. lower than had been intended, so that the rates of application on the sprayed plots were

[1] In this trial, nettles (*Urtica dioica*) were completely eradicated by 10 lb. MCPA per acre applied in October 1943, followed by 25 lb. MCPA per acre in May 1944. Later results showed that a single application of only 2 lb. MCPA per acre was sufficient to kill young nettles under certain conditions.

only 4½, 9, and 18 lb. per acre, the dust being applied at the full rates. Thistle counts were made just before treatment, again in September, and in June and September of the following year. For the first two counts a 12-in. square quadrat was thrown at random 10 times on each 1/100 acre plot; later, all plants on each plot were counted. The results, shown graphically in Fig. 1, indicate that approximately 80–90 per cent. control of thistles was achieved with 4½ lb. MCPA per acre as a spray, or 10 lb. MCPA per acre as a dust. The 5 lb. per acre dust treatment was inadequate.

1946–7 Experiment, Jealott's Hill. A second experiment, designed to compare the effects of spring, summer, and autumn applications of MCPA, was begun on an adjacent area in 1946. The experiment comprised 3 independent randomized blocks (one for each time of application), with 2 replicates of each treatment, MCPA being applied at 4, 8, or 12 lb. per acre as a spray or as a dust. The first application was made on April 30, when the thistles were 4–6 in. high and growing rapidly; the second on July 17, when they were 12–30 in. high and about to flower; and the third on October 14, when they were old and beginning to die back. Thistle counts were made in each case just before treatment, in October and in the following June. Except in April 1946, when the quadrat method was used, all the plants on each 1/100 acre plot were counted; although by June 1947 the density of thistles on some of the untreated plots was so great that this figure can only be regarded as approximate. The results (Table 1) show that 90–100 per cent. control was achieved with 4 lb. MCPA per acre as a spray or 8 lb. MCPA per acre as a dust, applied either in April or in July. The superiority of

TABLE 1. *Preliminary Trials with MCPA on Thistles, Jealott's Hill, 1946–7*

Treatment			*No. of thistles before treatment (per 1/100 acre)*	*No. of thistles Oct. 1946 (per 1/100 acre)*	*% killed (relative to untreated plots)*	*No. of thistles June 1947 (per 1/100 acre)*	*% killed (relative to untreated plots)*
MCPA lb./acre	*Dust (D) or spray (S)*	*When applied*					
0	..	..	860	670	0	1,000	0
4	D	Apr. 1946	810	110	83	280	70
8	D	,,	760	59	90	87	90
12	D	,,	630	10	98	28	96
4	S	,,	1,180	76	92	205	85
8	S	,,	980	43	94	77	93
12	S	,,	720	5	99	19	98
0	..	..	730	440	0	1,000	0
4	D	July 1946	1,160	650	7	380	76
8	D	,,	990	210	65	66	95
12	D	,,	930	260	54	18	99
4	S	,,	885	180	66	40	97
8	S	,,	1,175	180	75	36	98
12	S	,,	755	74	84	3	100
0	..	..	385	..	..	600	0
4	D	Oct. 1946	370	..	..	432	26
8	D	,,	270	..	..	210	50
12	D	,,	380	..	..	259	56
4	S	,,	600	..	..	885	5
8	S	,,	285	..	..	450	0
12	S	,,	320	..	..	291	42

spray over dust treatments was in agreement with the results of the previous experiment. October applications were unsatisfactory, even at 8 lb. MCPA per acre.

Preliminary trials at centres in southern England, 1945–6.—A series of unreplicated field trials at centres very near Jealott's Hill was begun in 1945 in order to obtain preliminary indications of the relative susceptibility to MCPA of the major grassland weeds. These were followed in 1946 by a second series of trials, in which dust and spray treatments of 2½, 5, and 10 lb. MCPA per acre were applied at various times of the year to duplicate 1/100-acre plots laid out in randomized blocks (Table 2). In each year thistles were the dominant weed in one trial and occurred in two others. The first year's results demonstrated that late autumn applications were quite ineffective for thistle control even at rates up to 20 lb. MCPA per acre, but in the second year May and June applications of 2½, 5, or 10 lb. MCPA per acre both produced a satisfactory kill. Dust applications were generally less efficient than spray, and in a few cases the 2½ lb. per acre rate applied as a dust was not enough.

TABLE 2. *Location and Details of Trials in Southern England, 1945–6*

Centre no.	*Location*	*Type of grassland*	*Dominant weed*	*Other weeds*	*Treatments tested*	
					lb. MCPA/acre (dust and spray)	*Times of application*
Trials begun in 1945						
1	Warfield, Berks.	Ley (1st year)	Thistles	Buttercups, sorrel	5, 10, 15, 20	Oct.
2	,,	Waste ground	Ragwort	Sorrel, &c.	2, 4, 8, 12, 16, 20	July
3*a*	Easthamstead, Berks.	Rough 3-year ley	Ragwort	Sorrel, docks	5, 10, 15, 20	Oct.
3*b*	Easthamstead, Berks.	Permanent pasture	Buttercups	Thistles	2, 4, 6, 8	Nov.
3*c*	Easthamstead, Berks.	Parkland	Bracken	..	5, 10, 15, 20	Oct.
4	Winkfield, Berks.	Permanent pasture	Docks	Chickweed, buttercups, thistles	4, 8, 12, 15	Nov.
Trials begun in 1946						
5*a*	Hurst, Berks.	Permanent pasture	Thistles	Buttercups, sorrel, &c.	2½, 5, 10	May, June, Sept.
5*b*	,,	3-year ley (2nd year)	Buttercups	Oxeye daisy, sorrel, &c.	2½, 5, 10	May, June, Sept.
6	Midgham, Berks.	Rough grazing	Ragwort	Buttercups, thistles, &c.	2½, 5, 10	May, June
7	Windsor, Berks.	Parkland	Bracken	Spear thistle, &c.	2½, 5, 10	June
8	Gamley, Leics.	Long ley (2nd year)	Docks	Thistles, buttercups, &c.	2½, 5, 10	May, July

RAGWORT (*Senecio jacobaea*)

Preliminary trials at centres in southern England, 1945–6.—Ragwort was dominant in two of the 1945 trials and one of the 1946 trials just described. In the first year, spray applications of 2 lb. MCPA or more per acre in July killed at least 80 per cent. of the ragwort, which was 3–4 ft. high and in flower at the time of spraying. Treatment at the end of October was even more effective, 5 lb. MCPA as a spray or 5–10 lb. MCPA per acre as a dust giving 90–95 per cent. control by the

following June. Heavier rates resulted in complete eradication. In the second year's trial, MCPA was applied on May 10 when the ragwort was not more than 6–12 in. high, and on June 14 when there was a dense infestation ranging from seedlings to the flowering stage. Application of 10 lb. MCPA per acre at the latter date, as spray or dust, gave good control; but lower rates were unsatisfactory. By late September there were still a few seedlings present on most of the plots treated in May.

Trials in northern England, 1946–7. Further trials were begun in 1946 at two centres in Yorkshire. In each case MCPA was tested at 2–4 lb. per acre applied as a dust in the late autumn or in the following spring, either alone or in conjunction with fertilizers (Table 3). Individual plots were 1/300 or 1/400 acre, with 3 or 4 replicates in a randomized block design. The average reduction in ragwort-stand resulting from MCPA treatment was 78 per cent., which was uninfluenced by fertilizer application. There was some indication that 4 lb. MCPA per acre might be more effective than 2 lb. MCPA per acre in spring, but not in autumn. At one centre (No. 10) the autumn applications gave significantly ($P > 0.01$) better ragwort control than the spring applications.

TABLE 3. *Results of Ragwort Trials in Northern England, 1946–7*

Centre	*Treatment*	*Ragwort density on untreated plots (flowering plants per 1/100 acre)*	*Percentage kill by MCPA at different rates* (lb./acre)*		
			2	*3*	*4*
No. 9 (nr. Leeds, Yorks.)	MCPA applied Nov. 12	140	74	..	85
	Ditto (with 1 cwt. N/C per acre)	..	84	..	..
	MCPA applied Mar. 28	296	58	71	75
	Ditto (with 1 cwt. S/A per acre)	..	51	..	..
No. 10 (nr. Sedbergh, Yorks.)	MCPA applied Oct. 14	150	93	..	98
	MCPA applied May 23	128	61	..	83
	Ditto (with 1½ cwt. S/A and 3 cwt. supers per acre applied Apr. 30)	..	50	..	91

* Based on plant counts at the end of July.

Trials in southern England, 1947.—Two more trials were undertaken in 1947 to compare the effectiveness of dust and spray applications of MCPA and DCPA (2,4-D) in spring at 2–4 lb. per acre (Table 4). Individual plots were 1/200 acre, with 4 replicates. All treatments were applied in the latter half of May and plant-counts were made approximately 6 weeks later. Excellent control of ragwort was achieved, the average reduction in stand being 97 per cent. At both centres MCPA gave significantly better results when applied as a spray than as a dust, and at one centre (No. 11) 4 lb. MCPA per acre was more effective than 2 lb. MCPA per acre, the difference being statistically significant. At the other centre there was no significant difference between the two rates of application. DCPA was generally more effective than MCPA.

TABLE 4. *Results of Ragwort Trials in Southern England, 1947, Six Weeks after MCPA Treatment*

Centre	Treatment	Ragwort density on untreated plots (flowering plants per 1/100 acre)	Percentage kill by MCPA or DCPA at different rates			
			MCPA (lb./acre)		DCPA (lb./acre)	
			2	4	2	4
No. 11 (Gatwick, Sussex)	Spray	212	98	100	100	99
	Dust	..	96	100	99	100
No. 12 (Henley, Oxon.)	Spray	180	100	99	96	100
	Dust	..	93	89	98	98

BUTTERCUPS (Ranunculus spp.)

Preliminary trials at centres in southern England, 1944–6.—Buttercups were controlled by a single application of 5 lb. MCPA per acre at a centre at Sawbridgeworth, Herts., in 1944; they also occurred as a major weed in one of the trials listed in Table 2 in 1945 and 1946, and as a minor weed in two trials in 1945 and three trials in 1946. The first year's results indicated that good control could be achieved by spraying with 2 lb. MCPA per acre in the late autumn, dust treatments being less effective. In the second year's trials excellent control was obtained by spraying between May and September with 2½ lb. MCPA per acre. Dust treatments were again slightly less effective than sprays and in some cases 2½ lb. per acre as a dust was insufficient to prevent regrowth. There was little difference in susceptibility between *R. repens*, *R. acris*, and *R. scleratus*.

1946–7 Trials.—Nine more trials (Table 5) were begun in October 1946 to compare the effects of spring and autumn MCPA treatments, alone or in conjunction with fertilizers applied 2 weeks before. Each trial consisted of four randomized blocks, each of six plots 1/100–1/400 acre. MCPA was applied at 0, 2, and 4 lb. per acre as a dust at Centres 13–20 and as a spray at Centre 21; DCPA treatments were also included for comparison at Centres 13–14. Fertilizer application varied from centre to centre, but the average rate was equivalent to approximately 1 cwt. sulphate of ammonia, 1½ cwt. superphosphate, and ½ cwt. muriate of potash per acre. All plots were harvested at the hay stage, 1–2 months after the spring weedkiller dressing, buttercup yields being calculated from sample cuts equivalent to one-half to one-quarter of each plot. Apart from the autumn application at Centre 18, which was flooded during the winter when a nearby river overflowed its banks, and excluding Centres 13 and 20, where other weeds were included in the yield data, MCPA treatment resulted in an average reduction of buttercup yield of 74 per cent. There were no significant differences between the effects of MCPA and DCPA, and in only a few cases did 4 lb. MCPA per acre give significantly better control of buttercups than 2 lb. per acre. The results of fertilizer application were conflicting, sometimes

TABLE 5. *Results of 1946–7 Buttercup Trials when cut for Hay in 1947*

Centre no.	Location	Time of treatment	Weight of buttercups (cwt. D.M./acre)					
			Without fertilizer			With fertilizer		
			MCPA applied (lb./acre)			MCPA applied (lb./acre)		
			0	2	4	0	2	4
13	Shamley Green, Surrey	Autumn 1946	8·4*	5·6*	5·9*	7·4*	5·4*	2·7*
		Spring 1947	9·9*	7·1*	6·8*	10·7*	4·4*	2·5*
14	Dunsfold, Surrey	Autumn 1946	31·2	4·4	2·4	18·4	1·4	0·2
		Spring 1947	9·2	2·2	6·2	28·8	2·2	7·2
15	Brooksby, Leics.	Autumn 1946	2·2	0·6	0·2	3·5	0·4	0·2
		Spring 1947	1·6	0·4	0·2	2·5	0·5	0·1
16	Llandrindod Wells, Radnor	Autumn 1946	7·6	2·4	3·9	8·4	5·4	3·1
		Spring 1947	7·3	3·0	2·9	8·8	2·2	1·4
17	Bingham, Notts.	Autumn 1946	1·6	0·3	0·0	1·3	0·0	0·0
		Spring 1947	0·9	0·2	0·1	0·5	0·0	0·1
18	Keighley, Yorks.	Autumn 1946	3·7	3·5	3·5	4·2	4·1	4·7
		Spring 1947	3·2	1·6	1·1	4·9	1·7	1·5
19	Orton, Westmorland	Autumn 1946	3·7	0·7	1·0	4·2	3·2	0·0
		Spring 1947	4·5	1·1	1·2	3·1	2·3	0·4
20	Plant Protection Ltd., Fernhurst, Surrey	Spring 1947	(No autumn treatment at this centre) 8·1*	0·8*	0·7*	10·0*	3·0*	1·2*
21	Carrickfergus, Co. Antrim	Autumn 1946	9·6	4·4	5·6	8·4	7·6	3·4
		Spring 1947	4·4	2·6	1·0	..	..	..

* Figures marked with an asterisk include weeds other than buttercups.

increasing the effectiveness of MCPA treatment and sometimes decreasing it, so that no definite conclusions could be drawn. Taking everything into consideration, the most satisfactory treatment appeared to be a spring dressing of 2 lb. MCPA per acre coupled with a fertilizer dressing.

Buttercups (mostly *R. acris* with some *R. scleratus*) also occurred as a secondary weed in the ragwort trial at Centre 11, which was harvested in May 1948, 12 months after weedkiller application. The average reduction in buttercup yield resulting from MCPA or DCPA treatment was 81 per cent., 4 lb. MCPA per acre being the most effective of the treatments tested and spray applications being more efficient than dusts (Table 6).

TABLE 6. *Residual Control of Buttercups 12 Months after Treatment for Ragwort Control, Gatwick, 1948*

Treatment	Weight of buttercups (fresh weight) cwt./acre		
	Average	Spray treatments	Dust treatments
Nil	11·34	..	..
MCPA 2 lb. per acre	2·16	0·95	4·83
DCPA 2 lb. per acre	3·02		
MCPA 4 lb. per acre	0·69	1·05	2·06
DCPA 4 lb. per acre	2·57		

DOCKS (*Rumex obtusifolius*, *R. crispus*) and SORREL (*R. acetosa*, *R. acetosella*)

Preliminary trials at centres in southern England, 1945–6.—Docks occurred as a major weed in one of the preliminary trials in 1945 and again in 1946; sorrel was a minor weed in three of the trials in each year. Summer and autumn applications of MCPA, even at 20 lb. per acre, proved ineffective against either weed in the mature stage; but at one centre seedling docks were almost entirely eliminated by a July application of 2½ lb. MCPA per acre. Late spring (May) treatment was generally more satisfactory, spray applications of 2½–10 lb. MCPA per acre controlling seedling docks and 10 lb. MCPA per acre giving at least partial control of sorrel. The latter weed was never completely eliminated, however, and both *R. acetosa* and *R. acetosella* must be regarded as somewhat resistant to MCPA. Dust applications were less effective than sprays.

1947 Trials.—Sorrel (*R. acetosa*), like buttercups, also occurred as a minor weed in the ragwort trial at Centre 11. In this instance the average reduction in yield resulting from MCPA or DCPA treatment 12 months earlier was 67 per cent., 4 lb. DCPA per acre being most effective (Table 7). Similarly, seedling docks, which occurred as a minor

TABLE 7. *Residual Control of Sorrel 12 Months after Treatment for Buttercup Control, Gatwick, 1948*

Treatment	*Yield of sorrel (fresh weight) cwt./acre*		
	Average	*Spray treatments*	*Dust treatments*
Nil	2·49	..	..
MCPA 2 lb. per acre	1·74	0·67	1·87
MCPA 4 lb. per acre	0·77		
DCPA 2 lb. per acre	0·21	0·43	0·39
DCPA 4 lb. per acre	0·63		

weed in the buttercup trial at Centre 20, were well controlled by MCPA at 2–4 lb. per acre, as judged by an analysis of the herbage in November, 6 months after treatment (Table 8). Plantains (Plantago spp.) were also controlled, but not self-heal (*Prunella vulgaris*).

TABLE 8. *Residual Control of Docks 6 Months after Treatment for Buttercup Control, Fernhurst, 1947*

Treatment 7.5.47	*No. of plants per 1/100 acre 10.11.47*		
	Rumex spp.	*Plantago spp.*	*Prunella vulgaris*
Nil	13·1	19·3	16·3
MCPA 2 lb. per acre	3·1	3·5	9·7
MCPA 4 lb. per acre	2·0	4·9	10·8

BRACKEN (*Pteridium aquilinum*)

In one unreplicated trial in 1945 applications of 10, 15, and 20 lb. MCPA per acre in October to freshly cleared ground, from which mature bracken had been cut and removed, gave partial control, estimated in the following July at 50–70 per cent. In a second trial, June applications not exceeding 10 lb. MCPA per acre to young bracken about 2 ft. high were relatively ineffective, causing little more than slight stunting and distortion.

Discussion

These experiments have shown that three of the worst grassland weeds (creeping thistles, ragwort, and buttercups) can be controlled by suitable applications of chlorinated phenoxyacetic acids, and that docks and sorrel can be checked under certain conditions, provided they are treated in the seedling stage.

Creeping thistles have proved to be most susceptible just as they are coming into flower, a result in agreement with the findings of Blackman [4, 5]. Excellent control has also been obtained by treatment at a somewhat earlier stage, when the weeds are 4–6 in. high and growing rapidly. Autumn applications, when the plants were old and beginning to die back, were entirely unsatisfactory. Under English conditions 4–5 lb. MCPA sodium salt per acre applied in June as a spray in 100 gals. water per acre has been the most effective treatment, little advantage being gained by raising the amount of active principle per acre above this level. Lower rates of application may sometimes be effective, but are generally inadequate to prevent rapid regrowth from underground roots, though they may successfully stop the plants from seeding [6]. In Northern Ireland, Morrison and Hale [7] observed resprouting as early as one month after treatment with rates less than 2 lb. per acre, despite a complete kill of top growth. Dust applications in chalk or similar inert material have not been as efficient as sprays and require, in general, double the amount of active principle per acre to produce the same effect. Similar results have been obtained in Holland by de Boer [8]. Spear thistles (*C. vulgare*) and Scotch or cotton thistles (*Onopordum acanthium*) are easier to kill than creeping thistles and usually require only 2 lb. MCPA per acre, particularly if sprayed when young.

Ragwort, too, appears to be most susceptible to these weedkillers when beginning to flower, but good control has also been obtained by treatment in the late autumn; 2–4 lb. MCPA (or DCPA) sodium salt applied in May as a spray or dust has generally given satisfactory results, though more may be needed where the infestation is severe. Work by Lynch [9] at the Rukuhia Soil Fertility Research Station, Hamilton, New Zealand, has demonstrated that under such conditions repeated application over a period of months may be the best treatment. Contrary to Lynch's results we have found dust applications quite effective. Edmunds and Jones [10], in trials conducted by the Pembrokeshire N.A.A.S., also obtained over 90 per cent. control of ragwort on plots treated in May with 3 lb. MCPA per acre in dust form. In general, however, spraying

may be expected to give slightly better results. Recent experience suggests that ragwort may be more difficult to control in a very dry season. It is of interest that the Swedish workers Osvald and Åberg [11] classify ragwort as resistant to both MCPA and the salts and esters of DCPA.

Buttercups (*R. repens*, *R. acris*, and *R. scleratus*) have been well controlled by spraying or dusting with 2 lb. MCPA per acre in the spring 2 weeks after applying fertilizers. Treatment later in the season has also given good results. MCPA appears to be more active against buttercups than DCPA, but both are relatively ineffective against the bulbous buttercup (*R. bulbosus*) except at very heavy rates of application. Spray treatments are generally more effective than dusts and, in some instances, it may be necessary to increase the rate of application in dust treatments to 3–4 lb. active principle per acre [12].

Broad-leaved docks (*R. obtusifolius*) and sorrel, though very resistant in the mature stage, have proved somewhat susceptible to applications of 4 lb. MCPA per acre as seedlings. Work in Italy [13] has shown that older plants of curled dock (*R. crispus*) are also susceptible.

Bracken has been injured by MCPA at rates up to 20 lb. per acre but has always recovered, a result which is in agreement with those of other workers [14, 15]. No better results have been obtained with DCPA.

Trials and demonstrations in Ireland [16, 17, 18] have shown that rushes (Juncus spp.) are quite susceptible and may be killed by applications of about 2 lb. MCPA per acre in June or July. The best results were obtained where the rushes were cut before the weedkiller was applied.

Of other grassland weeds knapweed (*Centaurea nigra*), silverweed (*Potentilla anserina*), yellow rattle (Rhinanthus sp.), and dandelions (*Taraxacum officinale*) appear to be moderately susceptible to 2–4 lb. MCPA per acre, and horsetails (Equisetum sp.), young oxeye daisies (*Chrysanthemum leucanthemum*), and hawkweeds (Hieracium spp.) to 4 lb. MCPA per acre. Older hawkweeds and oxeye daisies, together with brambles, gorse, broom, yarrow, mosses, and grasses, are resistant. The common daisy (*Bellis perennis*) is moderately resistant, but may be controlled in its young stages. Nettles (*Urtica dioica*) are also susceptible when young. Wild onions (*Allium vineale*) are fairly resistant, but in some instances top-growth has been completely killed by an application of 2–4 lb. MCPA per acre. The susceptibility of other grassland weeds is indicated in Table 9.

TABLE 9. *Susceptibility of Common Grassland Weeds to MCPA (sodium salt)*

Botanical name	*Common name*	*Susceptibility to MCPA (sodium salt)*
Achillea millefolium	Yarrow	r
Aegopodium podagraria	Ground elder	r
Ajuga reptans	Bugle	R
Allium vineale	Wild onion	r
Anthriscus sylvestris	Wild chervil	S
Arctium lappa	Burdock	r

Botanical name	*Common name*	*Susceptibility to MCPA (sodium salt)*
Bellis perennis	Daisy	r [s]
Cardamine pratensis	Lady's smock	?
Carex spp.	Sedge	?
Centaurea nigra	Knapweed	s
Cerastium vulgatum	Mouse-ear chickweed	r
Chrysanthemum leucanthemum	Oxeye daisy	R [s]
Cirsium arvense	Creeping thistle	s
Cirsium vulgare	Spear thistle	S
Colchicum autumnale	Meadow saffron	?
Daucus carota	Wild carrot	S
Dipsacus fullonum	Wild teazle	r
Equisetum sp.	Horsetail	s
Filipendula ulmaria	Meadowsweet	r
Galium verum	Lady's bedstraw	R
Geranium spp.	Cranesbill	r [s]
Heracleum sphondylium	Cow parsnip	?
Hieracium spp.	Hawkweed	R [s]
Hypochoeris radicata	Cat's-ear	s
Juncus spp.	Rush	S
Knautia arvensis	Field scabious	?
Leontodon spp.	Hawkbit	s
Luzula spp.	Woodrush	R
Malva spp.	Mallow	S
Onopordum acanthium	Cotton thistle	S
Plantago lanceolata	Ribgrass	S
Plantago major	Plantain	S
Potentilla anserina	Silverweed	s
Poterium sanguisorba	Salad burnet	R
Prunella vulgaris	Self-heal	r
Pteridium aquilinum	Bracken	R
Ranunculus spp. (except *bulbosus*)	Buttercup	S
Ranunculus bulbosus	Bulbous buttercup	r
Rhinanthus sp.	Yellow rattle	s
Rubus spp.	Bramble	R
Rumex acetosa	Sorrel	R [s]
Rumex acetosella	Sheep's sorrel	R [s]
Rumex crispus	Curled dock	s
Rumex obtusifolius	Common dock	R [s]
Sarothamnus scoparius	Broom	R
Senecio jacobaea	Ragwort	s
Taraxacum officinale	Dandelion	s
Tragopogon pratensis	Goat's-beard	s
Tussilago farfara	Coltsfoot	R
Ulex europaeus	Gorse	R
Urtica dioica	Nettle	r [S]
Veronica chamaedrys	Speedwell	r

S = moderately susceptible to 2 lb. MCPA per acre.
s = moderately susceptible to 4 lb. MCPA per acre.
r = fairly resistant to 4 lb. per acre.
R = resistant.
? = evidence inconsistent or inadequate.
Brackets indicate degree of susceptibility when young.

The effect of weed-control treatment with plant-growth regulators upon the productivity of grassland will be discussed in the next paper.

Summary

Field experiments are described in which infestations of creeping thistles, buttercups, and ragwort in grassland were controlled by suitably timed applications of the sodium salt of MCPA. In comparison with DCPA, MCPA appeared to be more effective against buttercups (except *R. bulbosus*) but slightly less effective against ragwort. Spray treatments generally had the same effect as dusts containing double the quantity of active material per unit area. Docks and sorrel were controlled only as seedlings and bracken not at all. The susceptibility of other weed species is indicated in the final table.

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STUDIES WITH SWEET CORN

V. SEED-SETTINGS WITH DISTANCES FROM POLLEN SOURCE

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AMONGST sweet corns used in England are the John Innes Hybrids obtained by hybridizing either Extra Early Bantam or Canada Gold with inbred C13. Some of the problems in hybrid-seed production need investigation as larger amounts are being produced. Two aspects requiring clarification are whether in seed-production plots comparatively more seed-rows can be introduced between pollen rows without reducing yield, and whether row-direction influences the amount of pollination. The general principles underlying the relation between pollination and seed-setting with a distant source of pollen also require investigation.

Experimental Data

Previous pollination experiments with maize, when studying spatial isolation necessary between seed-plots, have used competition between pollens from different sources, using marker genes such as starchy-sugary (*Su*/*su*) or yellow-white (*Y*/*y*) to show the amount of contamination with distance. However, as starchy and sugary pollens show selective fertilization [1], and as competition in hybrid plots is required only between sugary pollen, it was decided to determine the relation of seed-setting with distance using pollen of the same variety. To reduce variation of ear-size and row-number, which would influence the number of ovules on the ears, a hybrid variety Seneca 60 (Hart and Vick) was used. Originally seeds were sown directly in the ground in May, but owing to severe damage by frit fly [2] seeds had to be resown in pots. When the seedlings were sufficiently grown they were transferred to the open ground in a walled garden at Merton on July 12, 1949.

The experimental design used was similar to that of Bateman [3]. There was a central block consisting of 11 rows with 11 plants in each, with spacing of 1 ft. in either direction; this comprised the pollen source of 121 plants. Stringers were planted radiating in eight compass directions, each consisting of 11 plants spaced 4 ft. apart, the first plant being 4 ft. from the pollen block. The length of each stringer was thus 44 ft. This was fixed, partly owing to the amount of land available, and also because Bateman [3] had already shown that contamination was very low at greater distances, and we were not concerned with very low seed-setting.

Pollen-bearing tassels on plants along stringers were removed so that pollen came only from the central mass. Ripening seeds on the main ears of each plant were counted in September. These values are given in the diagram (due to A. Persson) in Fig. 1.

Here it is seen that, in general, the farther from the pollen source the

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less is the amount of seed that had set. The only exception is that of the NE. stringer where plants 32–40 ft. away from the source produced a high yield of seed. This could be due to the effect of the prevailing wind. An analysis of variance on the data was therefore made (Table 1), and it showed that the mean square for distances compared with the

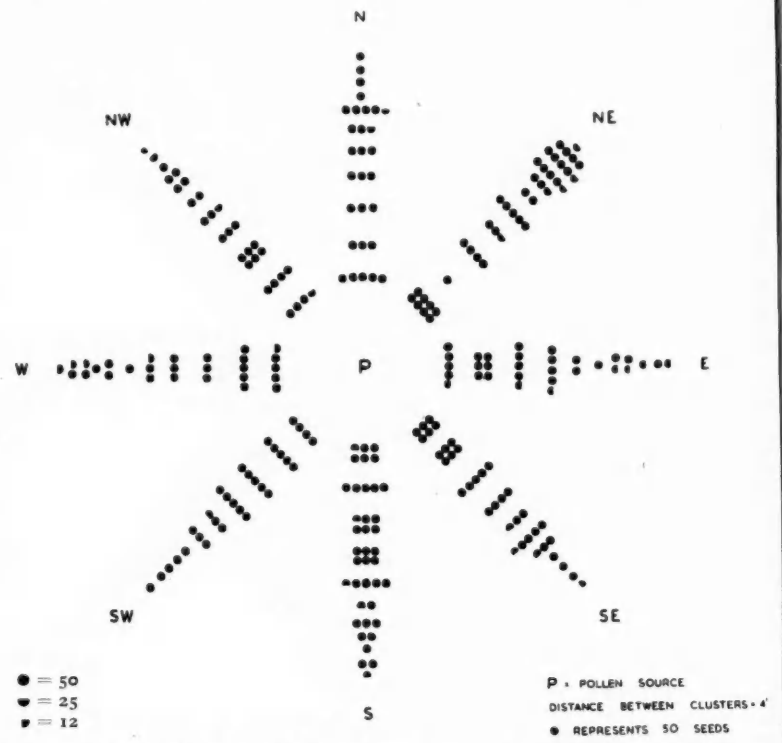

FIG. 1. Relation between seed-setting along stringers of detasselled sweet-corn plants and distance from a central pollen source. Each spot represents 50 seed and clusters are 4 ft. apart.

error mean square gave a highly significant value, P being less than 0·001, whilst that for the mean square for directions gave a value of $P = 0{\cdot}02$, which is not significant.

The indication that direction of stringers did not play a significant role in seed-setting was somewhat unexpected, but could perhaps be explained by the presence of high walls around the garden in contrast to open fields. These might have interfered with and nullified the effects of the wind. The wind directions in July and August are given in Table 2, and it is seen that between the period of pollen-shedding and seed-harvesting the prevailing wind was SW. This could, therefore,

TABLE 1. *Analysis of Variance of Seed-setting*

	Sum of squares (S.S.)	*Deg. of freedom (N)*	*Mean square (S.S./N)*	*Variance ratio*	*Probability (P)*
Distance . . .	472,766	10	47,276·6	3·74	<0·001
Direction . . .	33,615	7	4,802·1	1·18	>0·20
Distance-direction (error)	237,267	70	3,389·5	..	..
Total . . .	743,648	87	..	..	..

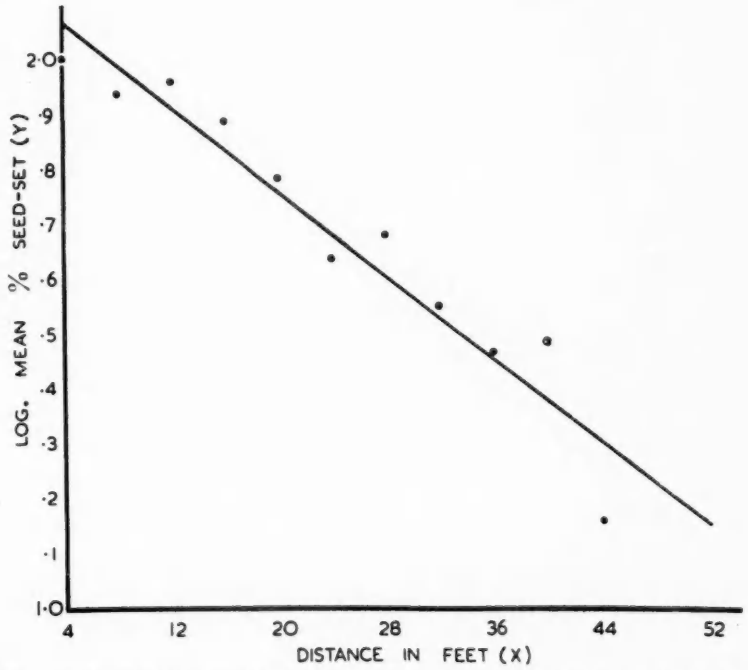

FIG. 2. The relation between the log. mean per cent. seed-set and distance from pollen source in feet. The straight line is the theoretical regression fitted to the data.

possibly explain the heavy yield on the NE. stringer. On the other hand this was not so with the NW. stringer, which showed a continual drop with distance, although the wind had also been blowing frequently from the SE.

The mean seed-set at each distance for all stringers was determined and, assuming 100 per cent. set for ears at 4 ft. from the pollen source, proportional settings for other distances were calculated. These produced a curve when plotted against distance. To smooth this, logs were taken and these plotted against distance (Fig. 2). It is seen that the

TABLE 2. *Direction of Prevailing Winds*

	SW.	*SE.*	*NW.*	*NE.*	*S.*	*E.*	*W.*
No. of days in July .	9	7	5	5	3	1	1
No. of days in August .	19	8	3	0	0	1	0
Total . . .	28	15	8	5	3	2	1

regression of log. mean percentage seed-set on distance from a pollen source is of the general form for a straight line $y = a+bx$. Irregularities in the graph, especially lower in the scale, are attributed to experimental error combined with use of logarithms, slight changes between lower numbers producing proportionally greater differences between their logarithms. The calculation for a negative linear regression was made [4] and this gave $y = 2{\cdot}1424-0{\cdot}075x$. This line is drawn in Fig. 2 and the field values fall closely along it; and it indicates, for instance, that at 60 ft. from the pollen source the seed-set is only about 10 per cent. of what it is at 4 ft.; more than 12 ft. from the pollen source is sufficient to reduce seed-setting to 80 per cent.

Discussion

Haber [5] made preliminary studies on how far apart plots of different types of maize should be planted to prevent contamination when growing hybrid sweet corn for seed. He provisionally classified ears into heavily and lightly contaminated from rows spaced $3\frac{1}{2}$ ft. apart, source of contamination being plants in an adjacent plot segregating purple aleurone colour. Heavy contamination was greatly reduced or ceased at 56 ft. Similarly, Mudra [6] studied the effects of row-number in decreasing contamination using the yellow-white (Y/y) factor. With row spacing of just under 2 ft. the amount of contamination of middle rows was 18·3 per cent. for 5 rows of each variety, 8 per cent. for 10 rows wide, and 2·5 per cent. for plots with 20 rows, using alternating plots of Y and y. He concluded that if the number of rows in the plot is increased to 50 the middle 20 to 25 probably will have under 1 per cent. contamination, which can hardly be attained by spatial isolation. Haskell [7] suggested that the recommended isolation distances between maize varieties grown for seed were more than sufficient. This was confirmed by Bateman [3], who found that maize pollen is not carried very far; at 60 ft. away from a pollen source, similar to that used in the above experiment, pollen-grain frequency in the air is reduced virtually to zero. From the regression line of Fig. 2 it is estimated that only 10 per cent. seed-set would be obtained at this distance, which is in fair agreement. Further tests might be made using pollen sources of different sizes and determining the relation between these and seed-setting at various distances.

The regression of log. seed-setting on distance, being a straight line, supports previous findings of Bateman [8] that contamination of his N. and S. stringers, using the *Su/su* factor, was a straight-line regression

on distance from source. This also indicates that both methods are satisfactory, and pollen competition effects are not important in experiments of this kind. The formula $y = a+bx$ is commonly found in the dispersal of small organisms [9].

In applying the above results to hybrid-seed production plots, it is clear that providing the detasselled seed-bearing plants are not more than 10 ft. away from a pollen source there is no danger of seed-yield dropping below 95 per cent. of the maximum. Thus, if rows in these plots are spaced 2 ft. apart, at least 5 rows of the seed parent (S) to one or two of the pollen parent (P) would guarantee sufficient pollen present for full pollination. This also allows for exigencies of climate, and the behaviour of inbred C13 and its time of pollen-shedding in relation to silking of either Extra Early Bantam or Canada Gold. This means that the layout $P\ S\ S\ P$ suggested by Haskell [10] is over-cautious and seed-rows could safely be increased from 2 to 5 between pollen rows.

Failure to find significant differences between stringers radiating from a pollen source indicates that in small hybrid-seed plots row-direction is not of great importance. Row-direction can therefore be adjusted to field conditions without interfering with pollination and seed-setting providing other conditions for these are fulfilled.

Summary

Sweet-corn plants, spaced 4 ft. apart in 8 stringers 44 ft. long radiating from a central pollen mass, were grown to determine the factors influencing setting in the production of hybrid seed. A hybrid variety was used to reduce error from inter-plant variation. Plants in stringers were detasselled and later the number of seeds on main ears counted.

Regression of seed-set against distance was a slight curve straightened by logs. A theoretical straight line ($y = a+bx$) was fitted to the data; this form is general for dispersal of small organisms. There was no significant difference for seed-set between stringers, perhaps due to walls reducing wind effects, but distance from source was highly significant. Seed-setting dropped to 95 per cent. at 12 ft. from pollen source and at 60 ft. was calculated to be only 10 per cent.

The number of seed-rows between pollen rows in hybrid-seed plots could be increased from 2 to 5 without loss of potential seed-yield. Row-direction is not important in small plots.

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THE NUTRITIVE VALUE OF CONOPHOR CAKE-MEAL FOR YOUNG DAIRY STOCK AND FATTENING PIGS

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Tetracarpidium conophorum is a plant growing in Nigeria. The kernels of this plant, which are eaten by the natives and are apparently non-toxic, are rich in oil. The oil present in the seeds has already been shown by technical trials to be superior to linseed oil for use in the paint and allied industries. After extraction of the oil the residue, 'conophor cake', has a high protein-content.

The supply of kernels is at present limited to a few tons annually, collected in a more or less haphazard manner from wild fruits. Before any plans can be made for increasing this supply by cultivation of the plant, it is important to determine the commercial value of the residual cake as well as that of the oil. For this purpose it was considered advisable to investigate the nutritive value of conophor cake for farm livestock.

After pilot experiments on small animals, carried out at the suggestion of the Colonial Products Research Council, the Board of Trade kindly placed at our disposal a small consignment of conophor cake-meal, obtained by native collection, sufficient to allow us to undertake small-scale trials of its nutritive value for young dairy cattle and for fattening pigs.

The conophor cake-meal tested was the residue left after solvent extraction of oil from the conophor kernels. Immediately after collection, the kernels were heated to 100° C. in order to destroy the enzymes present and so prevent the risk of hydrolysis of the oil or other useful constituent. During the extraction process no pressure was applied and during treatment the temperature never exceeded 115° F. After extraction the residue was drained, dried, and ground to a meal.

The chemical composition of the conophor cake-meal is given in Table 1, which also gives the composition of a sample of decorticated groundnut meal that was used in one of the feeding trials for comparison.

TABLE 1. *The Chemical Composition of Conophor Cake-meal and Decorticated Groundnut Meal (per cent.)*

	Conophor cake-meal	*Decorticated groundnut meal*
Moisture . . .	9·03	12·55
Crude protein . .	45·91	48·14
Ether extract . .	2·89	1·49
Soluble carbohydrates .	25·93	28·80
Crude fibre . . .	6·88	4·15
Ash	9·36	4·87

The chemical composition shows that the protein-content of the two meals is of the same order, and in other respects they are sufficiently alike to justify the expectation of similarity in nutritive value. There remains, however, the possibility of marked differences in the physiological availability of the two foods; any differences of this nature should be demonstrated by feeding trials.

Experiment with Young Dairy Cattle

The feeding trial consisted of a direct comparison between conophor cake-meal and decorticated groundnut meal, the latter being well known as a valuable cattle food.

Twelve Dairy Shorthorn heifers, ranging in age from 6 to 13 months, were used. They were paired to match as closely as possible in respect of age and initial live-weight. One member of each pair was allocated at random to receive conophor cake-meal as the chief source of protein in its ration, and the other received groundnut meal.

The animals were housed in pens. They were tied up during the day to allow controlled feeding and were loose at night when they had access to water.

The experimental ration consisted of: mangolds, 10 lb.; crushed oats, 1 lb.; conophor cake-meal or decorticated groundnut meal, 2 lb.; hay, 5–14 lb., according to size of animals to meet normal nutritive requirements. The exact amount is noted in Table 2.

This ration was started on March 22, 1950, and was continued for 7 weeks.

TABLE 2. *Rations and Live-weight Increases of Experimental Animals*

No. of animal	*Age on 22.3.50 (days)*	*Code letter of pair*	*Weight of hay in ration per day*	*Initial live-wt.*		*Live-wt. increase in 49 days*	
				D.G.M. group (lb.)	*Conophor group (lb.)*	*D.G.M. group (lb.)*	*Conophor group (lb.)*
85	240	A	5 lb. increasing to 7 lb.	..	387	..	90
86	215			359	..	45	..
90	194	B	5 lb. increasing to 7 lb.	..	344	..	60
87	207			343	..	59	..
74	373	C	10 lb. increasing to 14 lb.	..	572	..	91
75	369			601	..	76	..
76	369	D	10 lb. increasing to 12 lb.	..	544	..	73
72	402			551	..	66	..
79	351	E	8 lb. increasing to 10 lb.	..	471	..	58
78	357			516	..	66	..
84	302	F	8 lb. increasing to 10 lb.	..	447	..	79
81	324			475	..	55	..
Mean	..	..	..	..	..	61·2	75·2

It will be seen that the mean live-weight increases in 49 days were 61·2 lb. for the decorticated groundnut meal group, and 75·2 lb. for the conophor cake-meal group. The apparent slight advantage of the conophor group was not statistically significant (a difference of 27·9 lb. would

indicate significance when $P = 0{\cdot}05$), but the results suggest that the nutritive value of the conophor cake-meal was at least equal to that of decorticated groundnut meal.

The conophor cake-meal was readily eaten and appeared to be an entirely satisfactory food for young dairy stock.

Experiment with Pigs

The aim of this experiment was to ascertain the effect on rate of growth and food-utilization of the partial replacement of fish-meal in the diet of fattening pigs by conophor cake-meal.

Eighteen pigs from 4 litters were divided into 3 groups of 6 pigs each. In each group there were 4 female and 2 male pigs and their average initial weight was approximately the same. One of the 3 experimental meal mixtures was allocated at random to each of the 3 groups. The composition of the meal mixtures is given in Table 3.

TABLE 3. *Meal Mixtures used in the Experiment with Pigs (Composition per cent.)*

Group	*1*	*2*	*3*
Meal mixture	*K (control)*	*E*	*F*
Wheat feed	30	30	30
Barley meal	45	41	40
Flaked maize	15	15	15
White fish-meal	10	5	3
Conophor cake-meal	..	7	10
Limestone	..	$1\frac{1}{2}$	$1\frac{1}{2}$
Salt	..	$\frac{1}{2}$	$\frac{1}{2}$

Six oz. of cod-liver oil were added once weekly directly to each trough.

Each of these meal mixtures provided approximately the same amount of crude protein (about 16 per cent.). Complete replacement of fish-meal was not attempted, as it is well known that, for pigs, protein of vegetable origin is inferior to that of animal origin, unless fed in conjunction with small quantities of material supplying the animal-protein factor. As conophor cake-meal, in comparison with fish-meal, is a poor source of minerals, meal mixtures 2 and 3 were supplemented with limestone and salt. The experiment lasted 15 weeks (from April 10 to July 24, 1950). The results are summarized in Table 4.

All the pigs (with one exception) appeared healthy and grew well throughout the experimental period. The pigs receiving the conophor cake-meal obviously found it palatable, as no refusals of food occurred at any time. One pig in Group 2 for an unknown reason was off its food for some time during the test, and its growth was retarded. However, data concerning this pig are included in the average for the group as it was established that their omission would not materially alter the conclusions. It is clear that there was no marked difference between the three

experimental groups in the rate of growth of the pigs or in the efficiency with which they utilized their food.

TABLE 4. *Mean Live-weight Gain and Food Utilization of the Pigs in the Three Experimental Groups*

Group	1	2	3
Meal mixture	*K*	*E*	*F*
No. of pigs	6	6	6
Initial wt. (lb.)	77·7	78·5	77·2
Final wt. (lb.)	224·7	220·2	224·7
Gain in 15 weeks (lb.)	147·0	141·7	147·5
Daily gain (lb.)	1·4	1·35	1·4
Pounds of meal consumed for 1 lb. live-wt. gain	3·9	3·9	3·8

The saving of fish-meal in Group 3 as compared with the control group was approximately 40 lb. per pig. The common practice of reducing the protein supplement for older pigs was not followed in this test. Nevertheless, the data indicate that a substantial economy in fish-meal for fattening rations can satisfactorily be attained by appropriate replacement with conophor cake-meal.

Summary

1. Conophor cake-meal is a dried and ground residue obtained after extraction of oil from kernels of the plant *Tetracarpidium conophorum*, which grows in Nigeria but is not yet cultivated. Preliminary trials are reported here to indicate its nutritive value.

2. A feeding experiment with young dairy cattle showed that the conophor cake-meal was palatable and was at least equal in nutritive value to decorticated groundnut meal.

3. A feeding experiment with pigs showed that replacement of part of the fish-meal in a normal pig ration with conophor cake-meal, supplemented with limestone and salt, did not cause any decrease in live-weight gain or in the efficiency of food utilization.

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RESPONSE OF AN ESTABLISHED SHEEP LEY TO DRESSINGS OF SULPHATE OF AMMONIA

PART I. YIELDS AND BOTANICAL COMPOSITION OF HERBAGE CUT FOR SILAGE AND FOR HAY

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NUMEROUS investigations [1, 2, 3, 4] have shown that nitrogenous fertilizers bring about variable increases in the yield and crude-protein content of a pasture. The depression of the leguminous species caused by nitrogen has been amply confirmed [1, 2, 4]. Watson *et al.* [3] and Blackman [5] have shown that nitrogen can be used to produce grass earlier than normal in the spring. Lewis [6] found that soluble nitrogenous fertilizers applied to a hay-crop some 7–20 days before the crop was cut increased the crude-protein content of the hay. In all these investigations little attention has been paid to the optimum date for applying the nitrogen. Richardson [4] found that winter and spring applications of sulphate of ammonia produced increases in yield in the first and second cuts of herbage mown repeatedly. Winter applications produced less increase in yield and in nitrogen-content of the herbage than did spring applications. A late autumn application was almost as effective as a spring one.

The present study was concerned with differential dressings of sulphate of ammonia applied over a wide range of dates. Particular attention was paid to the 'out of season' applications for studying the effects on botanical composition of sulphate of ammonia applied during the months when the clovers are not actively growing.

The experimental area had been sown to a ley in the spring of 1943 under a nurse-crop of wheat. In the first harvest-year the ley was put up for hay and in the second year it was grazed. The chief contributor to the sward was perennial ryegrass, with some proportion of timothy and red and white clovers. The sward was in poor condition, open and generally lacking in vigour. The soil type was heavy clay (Lower Lias series) well supplied with lime: pH values ranged from 6·5 to 8·0. There was a natural deficiency of phosphate, but normally sufficient potash for cereals and grass. In February 1946 the whole area was dressed with superphosphate at 5 cwt. per acre. Following this phosphate application the area was divided into 160 plots of 1/40 acre (11 × 11 yds.) There were four manurial treatments, 0, 1, 2, and 4 cwt. of sulphate of ammonia per acre. For each level of nitrogen there was one plot dressed per month over the period February to November inclusive, making a total of 30 plots together with 10 control plots. All plots were replicated four times and allocated at random within the experimental area. Each treatment was compared under two contrasting systems of management. Half of each plot was cut three times during the season for silage, in May, June, and September; the other half was cut for hay and aftermath in June and September respectively.

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In the silage cuts, samples were obtained by cutting a strip with a Ransomes 'Verge Cutter' mower through the centre of each plot. Hay-cuts were taken with the Allen autoscythe, the method of sampling being similar. The fresh sample of herbage was weighed immediately after cutting and two sub-samples taken, one for the determination of dry matter and crude protein, and the other for botanical analysis. The botanical sample was separated into perennial ryegrass, timothy, other grasses, white clover, red clover, and miscellaneous species. The separates were oven-dried at 150° F., and the percentage productivity was determined on a dry-matter basis.

Conditions were more favourable for growth in 1946 than in 1947. In 1946 the early spring period was relatively warm and dry in contrast with the cold wet spring of 1947. In January, February, and March 1947, there were heavy falls of snow, and the ground was covered for 42 days during these 3 months. August was abnormally wet in 1946 but very dry in 1947.

Yield of Herbage in 1946

The results presented in Table 1 show a significant response to 1 cwt. of sulphate of ammonia at each date of application. The increases due to this treatment were 370, 430, and 330 lb. of dry matter per acre for the February, March, and April applications respectively. There were increases for the 2- and 4-cwt. applications, although the additional response to the second cwt. of sulphate of ammonia was very slight. Observations recorded on May 13 indicated that the plots manured in April were as forward in growth as the plots that had been manured in February and March. Yields of silage cut in May confirmed these observations.

TABLE 1. *First Silage cut May 14, 1946*

Yield of dry matter in lb. per acre

Rate of application of S/A (*cwt. per acre*)	*Time of application*			*Average*	
	Feb. 27	*Mar. 25*	*Apr. 16*		
Nil	..	..	..	889	±63
1	1,255	1,317	1,219	1,264	
2	1,288	1,442	1,486	1,385	
4	1,794	1,764	1,600	1,719	
	Standard error = ±110				
Average	1,446	1,508	1,435	±63	

Averages for the nitrogen treatments show that the response to the 4 cwt. of sulphate of ammonia was greater than all other rates of application. There were no differences between the 1- and 2-cwt. rates of application.

In the second silage cut (Table 2), the average response to 1 and 2 cwt. of sulphate of ammonia over February, March, and April was slight, indicating that the applications had been almost fully utilized in the first

silage cut. An application of 4 cwt. in those months, however, gave a 30 per cent. increase in yield, suggesting that a 4-cwt. application early in the spring can still contribute to the productivity of the sward in a second silage cut. There was on the other hand no abnormality in the shape of the response to the May applications, although the actual increases were not quite as large as might have been expected. This was probably due to not allowing the sward sufficient time between applying the nitrogen and cutting to make full use of the fertilizer. It could not be attributed to the lack of rainfall in May, which was more than sufficient for normal growth.

TABLE 2. *Second Silage cut June 25 1946*

Yield of dry matter in lb. per acre

Rate of application of S/A (cwt. per acre)	*Time of application*				*Average*
	Feb. 27	*Mar. 25*	*Apr. 16*	*May 16*	
Nil	..	..	..	..	2,104
1	2,174	1,908	2,232	2,502	2,204 ±106
2	1,998	2,318	2,469	2,685	2,368
4	3,017	2,619	2,968	2,929	2,883
	Standard error = ±213				
Average	2,396	2,282	2,556	2,705	±123

Data for the third silage cut that followed the June, July, and August applications of nitrogen and all other previous applications are given in Table 3. The small response to the February, March, April, and May applications, in many cases a negative one, suggested that the supply of nitrogen had already been fully utilized. In these months the negative response to the 4 cwt. of fertilizer may be partly attributed to the poorer growth of the clovers on these plots. The nitrogen applied in June, July, and August, even at 4 cwt. per acre, gave a very poor response, probably due to the two previous cutting treatments having left the sward in an exhausted condition and unable to respond to nitrogenous dressings. Four cwt. of sulphate of ammonia in June and July gave an

TABLE 3. *Third Silage cut September 19, 1946*

Yield of dry matter in lb. per acre

Rate of application of S/A (cwt. per acre)	*Time of application*								*Average*
	Feb. 27	*Mar. 25*	*Apr. 16*	*May 16*	*Average*	*June 29*	*July 23*	*Aug. 20*	
Nil	..	..	..	..	1,304	..	..	..	1,415
1	1,215	1,419	1,356	1,258	1,312 ±62	1,397	1,819	1,454	1,557 ±71
2	1,404	1,380	1,318	1,204	1,327	1,423	1,358	1,539	1,440
4	1,180	1,401	1,244	1,282	1,277	1,601	1,660	1,442	1,568
	Standard error = ±124								
Average	1,266	1,400	1,306	1,248	..	1,474	1,612	1,478	..
	Standard error for date means = ±71								

increase of 200 and about 250 lb. of dry matter per acre respectively over the control plots. Such an increase did not justify the amount of nitrogen applied. These results indicate that where the sward is in a poor and exhausted condition applications of nitrogen, even at high rates, cannot be expected to promote a rapid increase in production. As the rainfall during these months was more than adequate for growth (August being an abnormally wet month) it is probable that a long rest period is required before the nitrogen can become effective. The comparatively high response to 1 cwt. of sulphate of ammonia in July cannot be explained.

The yields of hay (Table 4) following the February, March, April, and May applications show in all cases that there was a response to 1 cwt. of fertilizer resulting in increases of from 650 lb. of dry matter in March to 1,000 lb. in April with an average increase of 789 lb. for the 4 months. There was a response to a 2-cwt. application in all months, but only in March and April did 2 cwt. produce significantly more than 1 cwt. The average response to the 2 cwt. application of sulphate of ammonia was 1,466 lb. of dry matter per acre for the 4 months. The 4-cwt. application produced the heaviest yields of hay except when applied in May. The heaviest rate of application of nitrogen in that month did not produce a greater yield than the control. Since the rainfall in May was not acting as a limiting factor the time factor must have been the principal cause of the low response to 4 cwt. of fertilizer. These results indicate that where nitrogen is being applied to increase the productivity of the hay crop, May application is too late, March and April application giving the greatest response. At the lower rates of application the indications again were that an application in May hardly gave time for full response to take place.

TABLE 4. *Hay cut June 15, 1946*

Yield of dry matter in lb. per acre

Rate of application of S/A (cwt. per acre)	*Time of application*				
	Feb. 27	*Mar. 25*	*Apr. 16*	*May 16*	*Average*
Nil	..	..	..	..	2,491
1	3,282	3,140	3,491	3,206	3,280 ± 153
2	3,621	4,039	4,499	3,667	3,957
4	4,653	5,377	4,906	3,657	4,648
	Standard error = ±306				
Average	3,852	4,185	4,299	3,510	±176

Table 5 gives the aftermath yields following upon applications of sulphate of ammonia in June, July, and August, and the applications in previous months. The aftermath yields at all rates from the February, March, April, and May applications differed very little, the control plots giving the greatest yield. This indicated that the nitrogen fertilizer had no residual effect on the yield of aftermath even at the heavy rates. It

is, perhaps, remarkable that there was no residual effect even from the 4 cwt. application in May.

TABLE 5. *Aftermath Cut, September 19, 1946*

Yield of dry matter in lb. per acre

Rate of application of S/A (cwt. per acre)	*Time of application*								
	Feb. 27	*Mar. 25*	*Apr. 16*	*May 16*	*Average*	*June 29*	*July 23*	*Aug. 20*	*Average*
Nil	..	..	..	..	1,480	..	..	..	1,330
1	1,464	1,370	1,355	1,305	1,374 ±67	1,612	1,530	1,512	1,551 ±77
2	1,299	1,227	1,460	1,473	1,365	1,619	1,606	1,440	1,555
4	1,260	1,486	1,227	1,390	1,341	1,822	1,890	1,501	1,738
	Standard error = ±133								
Average	1,341	1,361	1,347	1,389	..	1,684	1,675	1,484	..
	Standard error for date means = ±77								

Applications of nitrogenous fertilizer in June and July gave the largest yields of dry matter per acre. At rates of 1 and 2 cwt. of sulphate of ammonia, the increase over the control was 280 and 290 lb. of dry matter per acre respectively for June and 200 and 280 lb. for July. The greatest response was from the 4-cwt. application, the corresponding increases being 490 and 560 lb. Applications in August, even at 4 cwt. per acre, resulted in very small increases in yield although August was an exceptionally wet month. Some burning of the herbage occurred after the August application of nitrogen especially at the higher rates. It is possible that this checked the growth of the grass, but it does not seem to offer a convincing explanation of the small increase in yield. The poor condition of the ley might have been accentuated by the cutting of a hay crop. Recovery and utilization of nitrogen was very slow on such a stand, and the more probable explanation of the low yields obtained lies in the short time lapsing between the date of application and of cutting, viz. 28 days. A period of such duration was too short for the sward to make the fullest use of the nitrogen if yield of dry matter is taken as a measure of the utilization of nitrogen.

The evidence from the hay and silage cuts was in agreement with the finding from the aftermath cut. Sulphate of ammonia applied a month, or even less, before cutting the sward did not bring about the same increases in yield as earlier applications. If growth conditions are satisfactory it is apparent that there is a certain minimum time-lag between applying the nitrogen and cutting the sward before beneficial results may accrue. Sulphate of ammonia applied 2 months or more before cutting brought about marked increases in yield as indicated by the 1946 data, suggesting that the minimum time between application of nitrogen and cutting lies between 1 and 2 months. It is suggested that nitrogen be applied 2 months before cutting.

Yield of Herbage in 1947

The yields from the first silage cut following application of sulphate of ammonia in September, October, and November of 1946, and March

and April of 1947, are given in Table 6. The application in February could not be made because the ground was covered with snow the whole of this month. A striking feature of the first silage cut was the small variation in yield from the three rates of nitrogen. Since the spring rainfall was adequate for optimum growth, the most satisfactory reason for the small response would be the low temperature prevailing at this time. All rates of nitrogen gave higher yields than the control plots. With the heavier rate the return per cwt. of sulphate of ammonia applied was much smaller, and although the yields from the spring applications of sulphate of ammonia were greater than those from the autumn, the differences between them were not significant. Richardson [4] found that a late autumn application of sulphate of ammonia was almost as effective as a spring one; it follows that autumn applications of this fertilizer can be utilized by plants for growth in the following spring.

TABLE 6. *First Silage cut May 15, 1947*

Yield of dry matter in lb. per acre

Rate of application of S/A (*cwt. per acre*)	*Time of application*						
	1946				*1947*		
	Sept. 30	*Oct. 24*	*Nov. 21*	*Average*	*Mar. 20*	*Apr. 16*	*Average*
Nil . .	Average for the control plots						1,177±142
1 . .	1,379	1,346	1,308	1,344	1,555	1,487	1,521
2 . .	1,485	1,311	1,481	1,425 ±123	1,516	1,730	1,623 ±150
4 . .	1,289	1,493	1,629	1,470	1,751	1,568	1,659
	Standard error = ±212						
Average .	1,384	1,383	1,473	..	1,674	1,595	..
	Standard error for date means = ±123						

The yields from the second silage cut are presented in Table 7. The 1, 2, and 4 cwt. per acre applications in 1946 and in March and April 1947 showed no residual effect of nitrogen on gross yields. It has been shown [2] that sulphate of ammonia applied in February is normally fully utilized by the end of May. Indications in this experiment were that applications in March and April were fully used by the middle of May. These results conflict with those of 1946 (Table 2), when there were residual effects of the early spring application at the 4-cwt. level in the second silage cut. An explanation of this has been offered by Gardner [2], who found that if there is a cycle, including a locking-up stage, in the utilization of applied nitrogen, it could come into action again later in the year. It is possible that this was what happened in 1946 to the nitrogen applied before the first cut.

The May application gave the greatest response, but only at 4 cwt. per acre was this response greater than that of any other rate. There was a very poor response to the May nitrogen at 1 and 2 cwt. per acre.

The hay yields (Table 7) follow upon the 1946 applications of sulphate of ammonia, and the March, April, and May applications in 1947. There was a good response to 1 cwt. at all dates, the maximum response being

TABLE 7. *Yields of Second Cut for Silage and for Hay cut July 2, 1947*

Yield of dry matter in lb. per acre

SECOND SILAGE CUT

Rate of application of S/A (cwt. per acre)	Time of application: 1946 Feb. 27	June 29	July 23	Aug. 20	Average	±	1946 Sept. 29	Oct. 24	Nov. 21	Average	±	1947 Mar. 20	Apr. 16	May 8	Average	±
Nil	Average for the control plots														1,350	±121
1	1,300	1,129	1,194	1,394	1,254	±56	1,345	1,482	1,231	1,353	±65	1,230	1,219	1,359	1,269	±65
2	1,317	1,457	1,359	1,328	1,365		1,334	1,339	1,353	1,342		1,341	1,348	1,498	1,396	
4	1,179	1,214	1,369	1,178	1,235		1,440	1,322	1,401	1,388		1,400	1,354	2,023	1,592	
	Standard error = ±112															
Average	1,265	1,267	1,307	1,300	..		1,373	1,381	1,328	..		1,324	1,307	1,626	..	
	Standard error for date means = ±65															

HAY

Nil	Average for the control plots														3,682	±199
1	3,893	4,390	3,806	4,013	4,026	±151	3,975	4,187	3,732	3,965	±176	4,300	4,535	4,200	4,345	±176
2	4,213	3,906	4,878	4,566	4,391		4,678	4,020	4,476	4,391		4,174	3,889	4,555	4,206	
4	3,875	3,580	3,958	4,073	3,872		4,779	4,237	4,663	4,560		4,689	4,511	4,194	4,465	
	Standard error = ±302															
Average	3,994	3,959	4,214	4,214	..		4,476	4,148	4,290	..		4,387	4,312	4,323	..	
	Standard error for date means = ±176															

from the spring dressings of fertilizer. The small variation in response from the 1, 2, and 4 cwt. was probably due to the impoverished condition of the ley as a result of the system of continuous removal of herbage to which it was subjected, and to depression of the legumes by sulphate of ammonia.

At the 2- and 4-cwt. level the autumn dressings resulted in a slightly greater production of dry matter than the spring dressings, but the differences between them were not significant. As in the first silage cut the 1946 autumn dressings appeared just as effective as those in the spring of 1947.

Botanical Composition

1946. At each cutting-date botanical samples of each treatment were taken and subdivided into the grass and clover species present. Many data were obtained, but as the botanical changes at each cutting treatment were very similar only Table 8 for the aftermath and third silage cut is included in the text. This table shows the botanical composition of these two cuts averaged for the 7 months of application (February to August). Full details of all the cutting dates are not included in the text, but may be consulted at the Grassland Research Station. The chief conclusions that may be drawn are that nitrogen at all rates caused an increase in the proportion of the sown grasses but the unsown grasses remained practically unchanged. At all rates of manurial application the proportion of timothy increased, the maximum increase being from the 4 cwt. of sulphate of ammonia. Both red and white clover were depressed at all rates, the depression being greatest at the higher rate. The depression of clover caused by applying 1 and 2 cwt. of sulphate of ammonia was very similar, although at the 2-cwt. level the depression was somewhat more marked. There were no differential effects from the two cutting treatments on the botanical composition.

TABLE 8. *Botanical Composition of the Third Silage (September 19) and Aftermath Cut (September 24) 1946. Percentage Productivity*

Rate of application of S/A (cwt. per acre) Average for 7 months (Feb. to Aug.)	*Perennial ryegrass*	*Timothy*	*Other grasses*	*Red clover*	*White clover*	*Miscellaneous species*
Nil: Sept. 19	41·8	9·2	5·3	13·7	28·7	1·3
,, 24	41·2	10·8	4·6	15·9	27·0	0·5
1: ,, 19	42·4	10·2	4·7	12·5	29·5	0·7
,, 24	44·1	12·5	4·5	12·5	25·5	0·9
2: ,, 19	43·7	13·0	6·7	11·3	25·0	0·3
,, 24	46·8	15·2	5·5	10·1	22·0	0·4
4: ,, 19	51·5	14·3	5·7	8·1	20·0	0·4
,, 24	52·8	19·0	4·6	9·3	14·0	0·3

1947. Table 9 gives the botanical composition of the hay-cut taken on July 2, 1947, and that of the second silage cut taken at the same time. Comparison is made between the effect of no nitrogen as against the

after effect of 1946 summer (June, July, and August) applications of sulphate of ammonia, 1946 autumn (September, October, and November) applications and 1947 spring (March, April, and May) applications.

TABLE 9. *Botanical Composition of the Hay and the Second Silage cut, July 2, 1947. Percentage Productivity*

HAY

Rate of application of S/A (cwt. per acre)	*Date and year when S/A was applied*	*Perennial ryegrass*	*Timothy*	*Other grasses*	*Red clover*	*White clover*	*Miscellaneous species*
Average control plots		24·7	25·8	6·8	23·5	17·3	1·9
1	1946 Summer	21·4	28·4	6·3	25·2	16·2	2·5
	1946 Autumn	27·8	31·0	8·4	18·0	11·3	3·5
	1947 Spring	23·3	33·5	11·1	18·0	11·5	2·6
2	1946 Summer	29·8	32·4	7·4	17·2	10·6	2·6
	1946 Autumn	29·0	31·6	9·8	15·7	12·1	1·8
	1947 Spring	28·7	35·0	9·3	16·3	8·4	2·3
4	1946 Summer	34·2	41·1	6·9	9·1	7·1	1·6
	1946 Autumn	30·7	38·9	8·4	11·7	7·3	3·0
	1947 Spring	28·4	45·7	10·1	7·4	6·5	1·9

SECOND SILAGE CUT

Average control plots		20·2	23·7	3·9	18·5	31·5	2·2
1	1946 Summer	23·3	27·8	4·0	19·7	21·5	3·7
	1946 Autumn	23·7	24·6	5·7	16·1	25·1	4·8
	1947 Spring	26·3	24·0	3·5	14·3	25·2	6·7
2	1946 Summer	21·3	25·1	5·6	19·0	24·8	4·2
	1946 Autumn	24·1	28·3	4·1	21·2	19·0	3·3
	1947 Spring	28·6	30·7	4·0	12·4	19·5	4·8
4	1946 Summer	28·0	36·3	3·6	13·6	14·9	3·6
	1946 Autumn	33·0	32·6	4·8	10·5	14·4	4·7
	1947 Spring	32·3	39·2	7·9	7·3	9·8	3·5

The data presented in Table 9 indicate that nitrogen application increased the proportion of perennial ryegrass, timothy, and the unsown grasses. The chief change from the botanical composition of 1946 was the increase in the proportion of timothy, even on the control plots, at the expense of ryegrass. The chief species among the unsown grasses were cocksfoot, crested dogstail, Poa and Agrostis species. Both red and white clover were depressed at all rates, the depression being greatest with the heaviest applications of sulphate of ammonia. In the first and second silage cuts 1 and 2 cwt. of fertilizer had very similar effects on the botanical composition, but 4 cwt. caused a more marked depression of the clovers and an increase in the grasses.

Both autumn and spring sulphate of ammonia had similar effects on the botanical composition at rates of 1 and 2 cwt. per acre. At 4 cwt. per acre the autumn applications of nitrogen had a less depressing effect on the legume than the spring applications, although the depression was still marked in each case. Richardson [4] found that 2 cwt. of sulphate of ammonia per acre applied to a sward in December had no depressing effect on the legume in the following July. The findings from this

experiment indicate that late autumn nitrogen applications are almost as effective in depressing the clovers as spring applications.

Summary

An account is given of the effect of applying sulphate of ammonia at 1, 2, and 4 cwt. per acre over a wide range of dates to a ley that was rapidly becoming outrun. Data were collected for two years, 1946 and 1947.

1. The amount of dry matter produced increased according to the amount of sulphate of ammonia applied, the largest production resulting from the 4-cwt. application. In 1947 there was less variation in the production of dry matter from the three rates of nitrogen.

2. When cutting for silage or hay it is suggested that to obtain higher dry-matter yields the nitrogen should be applied 2 months or longer before cutting; if applied less than a month before cutting there is not sufficient time for a full response in yield to occur.

3. In general, there was no residual effect of sulphate of ammonia after one cut upon the yield of subsequent cuts.

4. There were no differences between the yields of dry matter from autumn and spring applications.

5. Sulphate of ammonia brought about an increase in the proportion of the sown grasses; that of the unsown grasses remained practically unchanged. Red and white clover were depressed at all rates of application, the depression being greatest at the 4-cwt. level. There were no differential effects from the date of application of fertilizer on the botanical composition. Sulphate of ammonia, applied in September, October, and November, suppressed the clover almost as much as did spring nitrogen.

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RESPONSE OF AN ESTABLISHED SHEEP LEY TO DRESSINGS OF SULPHATE OF AMMONIA

Pt. II. EFFECTS ON CHEMICAL COMPOSITION OF THE HERBAGE

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The Crude-protein Contents of the Herbage Cut in 1946 *and* 1947 *1946.* That sulphate of ammonia at all rates raised the proportion of crude protein in the herbage is shown in Table 1. In February only the 4-cwt. application of sulphate of ammonia had any appreciable effect in raising the proportion of crude protein in the herbage. Applications in March did not raise the crude-protein content significantly; at all levels of fertilizer application in April it rose more than in any other month. It therefore seems probable that if the aim of such an application is to raise the percentage crude protein of the herbage then the nitrogen should be applied near to the cutting date. This bears out the work of Lewis, who found that late applications of soluble nitrogenous fertilizers to a hay crop raised the proportion of crude protein of the hay. For all rates of application of nitrogen the proportion of crude protein was higher than for the controls.

TABLE 1. *First Silage Cut, May 14, 1946*
Yield of Crude Protein and Percentage Crude Protein[1]
in Dry Matter (lb. per acre)

Rate of application of S/A (cwt. per acre)	*Time of application*			*Average*		
	Feb. 27	*Mar. 25*	*Apr. 16*			
Nil	..	..	..	113·1	(12·7)	
1	161·9 (12·9)	187·0 (14·2)	185·3 (15·2)	178·1	(14·1)	(±0·4)
2	166·2 (12·9)	194·7 (13·5)	239·2 (16·1)	200·0	±12·3 (14·2)	
4	283·5 (15·8)	248·7 (14·1)	284·8 (17·8)	272·3	(15·9)	
	Standard error = ±21·3 (±0·7)					
Average	203·9 (13·9)	210·1 (13·9)	236·4 (16·4)			
	S.E. for date means = ±12·3 (±0·4)					

[1] Percentage crude protein in brackets.

In yield of crude protein, the first silage cut shows that on the average the April application of fertilizer resulted in the greatest production (Table 1). The nitrogen-treatment means show that all rates gave a greater production of crude protein than the control. The 4 cwt. of fertilizer resulted in a greater yield than 1 and 2 cwt., but differences between the 1- and 2-cwt. dressings were not significant.

In the second silage cut (Table 2), if the average crude-protein percentages for the rates of application of sulphate of ammonia are

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considered, it is seen that the values increased with lowering rates of nitrogen, the highest percentage being from the control plots. After cutting the nitrogen-treated plots once, it appeared that it was the proportion of clover in the sward which determined the crude-protein content of the herbage. The heavy nitrogen dressings resulted in the lowest percentage of clover and generally the lowest crude-protein content. The low values for the 2-cwt. application of fertilizer in February and the 4-cwt. application in April were correlated with the low percentage of white clover present in these plots.

From the results of the first silage cut (Table 1) it was to be expected that May being the last date of applying the nitrogen, the May applications would at the heavier rates give marked increases in the crude-protein percentage. This, however, was not the case. The botanical data show that May application did not have a more depressing effect on the clover than any other. The low crude-protein value cannot be attributed to a greater depression of white clover. There are two possible explanations. During May and June when the grasses are passing through their phase of reproductive development it is difficult to maintain a high crude-protein content except at high levels of nitrogen application. More reliance at this period should be given to a sward dominated by a legume, as the control plots in general have given higher crude-protein values. Secondly, the time elapsing between applying the May nitrogen and cutting the sward was 36 days. Lewis has shown that soluble nitrogenous fertilizers raise the crude-protein content only when applied 7–20 days before cutting.

Yields of crude protein in the second silage cut are not consistent, but the averages for the rates and dates of application of fertilizer are more informative. These show that the 4-cwt. application of sulphate of ammonia produced more protein than any other rate. The yield of crude protein in May was higher than that of any other month. The larger production of dry matter in the nitrogen-treated plots (see Table 2, Pt. I) balanced the fall in the percentage crude protein except where the values fall acutely, as in the application of 2 cwt. in February and the 4 cwt. of April.

Percentage crude-protein figures for the third silage cut are given in Table 3. The averages for February, March, April, and May nitrogen show that the control plots had the highest percentage of crude protein, and that there was a corresponding decrease in crude protein with increased rates of nitrogen. It appears probable, therefore, that there are no residual effects of such applications in this third cut, so confirming the findings from the dry-matter yields. In July and August the treated plots gave higher crude-protein percentages than the control, but only at the heaviest rate in August was the increase significant. Late applications of nitrogen have the most marked effect on the crude-protein percentage, bearing out the findings from the first silage cut (see Table 1).

The yields of crude protein (Table 3) show that at the 4-cwt. level of sulphate of ammonia the largest production of crude protein resulted from the applications in June, July, and August. This is correlated with the higher yield of dry matter and crude-protein percentages produced

TABLE 2. *Second Silage Cut, June 25, 1946*
Yield of Crude Protein (in lb. per acre) and Percentage Crude Protein[1] in Dry Matter

Rate of application of S/A (cwt. per acre)	*Time of application*				*Average*
	Feb. 27	*Mar. 25*	*Apr. 16*	*May 16*	
Nil	.. ..	.. ..	.. ..	.. ..	295·0 (13·9)
1	302·2 (13·9)	246·1 (12·9)	321·4 (14·4)	265·2 (10·6)	283·7 (13·0) ± 20·2 (12·0) (±0·6)
2	175·8 (8·8)	315·2 (13·6)	355·5 (14·4)	319·5 (11·9)	291·5 (12·0)
4	389·2 (12·9)	272·4 (10·4)	240·4 (8·1)	410·1 (14·0)	328·0 (11·4)
	Standard error = ±40·5 (±1·2)				
Average	289·1 (11·9)	277·9 (12·3)	305·8 (12·3)	331·6 (12·2)	
	S.E. for date means = ±23·4 (±0·7)				

[1] Percentage crude protein in brackets.

TABLE 3. *Third Silage Cut, September 19, 1946*
Yield of Crude Protein (in lb. per acre) and Percentage Crude Protein[1] in Dry Matter

Rate of application of S/A (cwt. per acre)	*Time of application*									
	Feb. 27	*Mar. 25*	*Apr. 16*	*May 16*	*Average*	*June 29*	*July 23*	*Aug. 20*	*Average*	
Nil	.. ..	.. ..	.. ..	.. ..	247·4 (18·9)	.. ..	.. ..	.. ..	259·9 (18·4)	
1	224·8 (18·5)	283·8 (20·1)	248·1 (18·3)	225·2 (17·9)	245·5 (18·7) ± 12·3 (±0·5)	262·6 (18·8)	318·3 (17·5)	273·4 (18·8)	284·8 (18·4) ± 14·3 (±0·6)	
2	268·2 (19·1)	260·8 (18·9)	253·1 (19·2)	192·6 (16·0)	243·7 (18·4)	210·4 (18·3)	253·9 (18·7)	310·9 (20·2)	275·1 (19·1)	
4	221·8 (18·8)	235·4 (16·8)	210·2 (16·9)	216·7 (16·9)	221·0 (17·4)	283·4 (17·7)	325·4 (19·6)	301·4 (20·9)	303·4 (19·4)	
	Standard error = ±24·7 (±1·1)									
Average	238·3 (18·8)	260·0 (18·6)	237·1 (18·1)	211·5 (16·9)		252·1 (18·3)	299·2 (18·6)	295·2 (20·0)		
	S.E. for date means = ±14·3 (±0·6)									

[1] Percentage crude protein in brackets.

in these months. From March to May there was a general tendency for an increase in the yield of crude protein with decrease in the rate of nitrogen application owing to the high percentage of legumes in the control and in the lower-rate-of-application plots.

Data from the hay cut are presented in Table 4. February, March, April, and May applications of fertilizer have in general resulted in smaller crude-protein percentages than the control. Only in May, at the heaviest rate of application, was the proportion of crude protein greater than the control. These results suggest that the nitrogen applied in February, March, and April was utilized in the production of dry matter and that there was no surplus for raising the proportion of crude protein in the herbage. Sulphate of ammonia applied in May at 4 cwt. per acre was more than sufficient for the production of dry matter and so increased the proportion of crude protein in the herbage in addition.

TABLE 4. *Hay Cut, June 18, 1946*
Yield of Crude Protein (in lb. per acre) and Percentage Crude Protein[1] in Dry Matter

Rate of application of S/A (cwt. per acre)	*Time of application*				*Average*		
	Feb. 27	*Mar. 25*	*Apr. 16*	*May 16*			
Nil	.. ..	.. ..	.. ..	.. ..	258·7	(10·4)	
1	301·9 (9·2)	295·2 (9·4)	321·2 (9·2)	307·8 (9·6)	306·5	(9·4)	(±0·4)
2	362·1 (10·0)	302·9 (7·5)	431·9 (9·6)	359·4 (9·8)	364·1	(9·0)	
4	386·2 (8·3)	462·4 (8·6)	480·8 (9·8)	486·4 (13·3)	454·0	(10·0)	
	Standard error = ±42·7 (±0·8)				±21·3		
Average	350·1 (9·2)	353·5 (8·5)	411·3 (9·5)	384·5 (10·9)			
	S.E. for date means = ±24·7 (±0·5)						

[1] Percentage crude protein in brackets.

At all levels of application of sulphate of ammonia the yield of crude protein was greater than the control. The April and May applications resulted in the greatest production of crude protein. Reference to Table 4, Pt. I, shows that May nitrogen gave the lowest production of dry matter, but this was balanced by the higher percentage crude protein of the herbage at this time.

The crude-protein percentages from the aftermath cut are presented in Table 5. The control plots gave a higher percentage of crude protein than plots which received 4 cwt. of fertilizer applied in February, March, April, and May, and these increases were all significant. From this it seems probable that there was no residual effect from the February to May nitrogen.

The botanical data (Table 8, Pt. I) show that the control plots had the highest percentage of legume and correlated with this was their higher crude-protein percentages. The monthly averages show that August nitrogen resulted in a crude-protein percentage (19·2), which was significantly higher than in any other month. This confirmed the findings from the previous cuts that late applications of nitrogen have a marked effect on raising the crude-protein percentage.

TABLE 5. *Aftermath Cut, September 24, 1946*
Yield of Crude Protein (in lb. per acre) and Percentage Crude Protein[1] in Dry Matter

Rate of application of S/A (cwt. per acre)	*Time of application*								
	Feb. 27	*Mar. 28*	*Apr. 16*	*May 16*	*Average*	*June 29*	*July 23*	*Aug. 20*	*Average*
Nil	.. ..	.. ..	.. ..	.. ..	269·9 (18·2)	.. ..	.. ..	.. ..	232·2 (17·4)
1	254·7 (17·4)	246·6 (18·0)	249·3 (18·4)	211·4 (16·2)	240·5 ±12·7 (17·5) (±0·6)	254·7 (15·8)	249·4 (16·3)	287·3 (19·0)	263·8 ±14·7 (17·0) (±0·7)
2	210·4 (16·2)	231·9 (18·9)	233·6 (16·0)	223·9 (15·2)	225·0 (16·6)	262·3 (16·2)	263·4 (16·4)	265·0 (18·4)	263·6 (17·0)
4	197·8 (15·7)	188·7 (12·7)	171·8 (14·0)	182·1 (13·1)	185·1 (13·9)	293·3 (16·1)	332·6 (17·6)	304·7 (20·3)	310·2 (18·0)
	Standard error = ±25·5 (±1·1)								
Average	221·0 (16·4)	222·4 (16·5)	218·2 (16·1)	205·8 (14·8)		270·1 (16·0)	281·8 (16·8)	285·7 (19·2)	
	S.E. for date means = ±14·7 (±0·7)								

[1] Percentage crude protein in brackets.

TABLE 6. *First Silage Cut, May 15, 1947*
Yield of Crude Protein (in lb. per acre) and Percentage Crude Protein[1] in Dry Matter

Rate of application of S/A (cwt. per acre)	*Time of application*							
	1946				*1947*			
	Sept. 30	*Oct. 24*	*Nov. 21*	*Average*	*Mar. 20*	*Apr. 16*	*Average*
Nil	Average for the control plots = 210·7±22·9 (17·9±0·8)						
1	262·0 (19·0)	267·9 (19·9)	256·4 (19·6)	262·1 (19·5)	284·6 (18·3)	292·9 (19·7)	288·7 (19·0)
2	267·3 (18·0)	262·2 (20·0)	271·0 (18·3)	266·8 ±26·8 (18·7) (±0·6)	295·6 (19·5)	377·1 (21·8)	336·3 ±32·8 (20·6) (±0·8)
4	212·7 (16·5)	253·8 (17·0)	298·1 (18·3)	254·8 (17·3)	325·7 (18·6)	326·1 (20·8)	325·9 (19·7)
	Standard error = ±37·2 (±1·1)						
Average	247·3 (17·8)	261·3 (19·0)	275·2 (18·7)		302·0 (18·8)	332·0 (20·8)	
	S.E. for date means = ±21·5 (±0·6)						

[1] Percentage crude protein in brackets.

The yield of crude protein from the aftermath is also given in Table 5. The nitrogen-treatment averages from February to May show that the yield of crude protein fell with increasing rates of nitrogen, the maximum production being from the control plots. Nitrogen applied in these months lowered the yield of dry-matter and the crude-protein percentage, resulting in a fall in the production of crude protein. The cause of this was apparently the depressing effect of sulphate of ammonia upon the clovers. In June, July, and August there was an increase in the yield of crude protein with increasing amounts of fertilizer, the maximum production resulting from the 4-cwt. level. The treatment means for the dates of application of fertilizer show that the August applications gave a significantly greater production of crude protein than those in February, March, April, and May.

1947. Crude-protein contents of the first silage cuts are given in Table 6. The average crude-protein percentages for the months of application show that April nitrogen produced a significantly higher percentage crude protein than that of any other month. This corroborates the 1946 results, which showed that late applications of nitrogen were the most effective in raising the crude-protein content.

The spring dressings of fertilizer generally raised the crude-protein percentage above the control, but there were only small differences between the 1-, 2-, and 4-cwt. applications. March nitrogen was no more efficient in raising the crude-protein percentage than autumn nitrogen. Richardson found that spring nitrogen raised the percentage nitrogen-content of the herbage significantly but autumn dressings did not. The averages for the autumn applications show that there was a considerable response to 1 cwt. of fertilizer. The 4-cwt. applications produced a significantly lower percentage of crude protein than the 1-cwt. applications. This was probably correlated with the greater depressing effect of the 4 cwt. of sulphate of ammonia on the clovers.

Table 6 shows that all treatments gave a larger yield of crude protein than the control, but there were only small differences in yield between the 1-, 2-, and 4-cwt. applications. Spring applications of sulphate of ammonia at all rates yielded more crude protein than did autumn nitrogen. The average crude-protein yields for the 5 months of application show that there was a consistent increase from September to April.

In the second silage cut (Table 7) none of the treatments raised the crude-protein percentage above the control. The average percentages for the rates of nitrogen show that in all cases 4 cwt. of sulphate of ammonia resulted in the lowest percentage of crude protein. The cause of this was probably the low clover-content on the heaviest nitrogen-treated plots (Table 9, Pt. I). It was expected from the 1946 results that May nitrogen would result in the highest crude-protein values, but this was not the case. Apparently the May nitrogen was no more than could be used by the plant in building up dry matter.

In the yield of crude protein from the second silage cut, there was a general decrease following increases in the rate of application of sulphate

TABLE 7. *Second Silage Cut, July 2, 1947*
Yield of Crude Protein (in lb. per acre) and Percentage Crude Protein[1] in Dry Matter

Rate of application of S/A (cwt. per acre)	*Time of application*															
	1946										*1947*					
	Feb. 27	*June 29*	*July 23*	*Aug. 20*	*Average*			*Sept. 29*	*Oct. 24*	*Nov. 21*	*Average*			*Mar. 20*	*Apr. 16*	*May 8*	*Average*		
Nil	Average for the control plots = 186·3±20·9 (13·8±0·4)																		
1	169·0 (13·0)	149·0 (13·2)	158·8 (13·3)	188·2 (13·5)	166·2	±8·9	(13·3)	177·5 (13·2)	195·6 (13·2)	155·1 (12·6)	176·1	±10·3	(13·0)	155·0 (12·6)	168·2 (13·8)	195·3 (12·9)	172·8	±10·3	(13·1)
2	172·5 (13·1)	198·2 (13·6)	183·5 (13·5)	166·0 (12·5)	180·1		(13·2)	177·4 (13·3)	170·1 (12·7)	179·9 (13·3)	175·8		(13·1)	183·7 (13·7)	168·2 (12·5)	178·3 (11·9)	176·7		(12·7)
4	150·9 (12·8)	138·4 (11·4)	165·6 (12·1)	131·9 (11·2)	146·7		(11·6)	167·0 (11·6)	160·0 (12·1)	169·5 (12·1)	165·5		(11·9)	158·2 (11·3)	146·2 (10·8)	252·9 (12·5)	185·8		(11·5)
	Standard error = ±17·8 and (±1·2)																		
Average	164·1 (13·0)	161·9 (12·7)	169·3 (13·0)	162·0 (12·4)				174·0 (12·7)	175·2 (12·7)	168·2 (12·7)				165·6 (12·5)	161·0 (12·4)	202·2 (12·4)			
	S.E. for date means = ±10·3 and (±0·7)																		

TABLE 8. *Hay Cut, July 2, 1947*
Yield of Crude Protein (in lb. per acre) and Percentage Crude Protein[1] in Dry Matter

Nil	Average for the control plots = 349·8±33·2 (9·5±0·6)																		
1	358·2 (9·2)	425·8 (9·7)	346·3 (9·1)	401·3 (10·0)	382·9	±19·4	(9·5)	365·7 (9·2)	364·3 (8·7)	339·6 (9·1)	356·5	±22·3	(9·0)	412·8 (9·6)	380·9 (8·4)	375·6 (8·9)	389·8	±22·3	(9·0)
2	417·1 (9·9)	339·8 (8·7)	390·2 (8·0)	424·6 (9·3)	392·9		(9·0)	397·6 (8·5)	365·8 (9·1)	398·4 (8·9)	387·3		(8·8)	359·0 (8·6)	353·9 (9·1)	423·6 (9·3)	378·8		(9·0)
4	372·0 (9·6)	275·7 (7·7)	277·1 (7·0)	301·4 (7·4)	306·6		(7·9)	368·0 (7·7)	360·1 (8·5)	382·4 (8·2)	370·2		(8·1)	412·6 (8·8)	374·4 (8·3)	402·6 (9·6)	396·5		(8·9)
	Standard error = ±38·7 (±0·4)																		
Average	382·4 (9·6)	347·1 (8·7)	337·9 (8·0)	375·8 (8·9)				377·1 (8·5)	363·4 (8·8)	373·5 (8·7)				394·8 (9·0)	369·7 (8·6)	400·6 (9·3)			
	S.E. for date means = ±22·3 (±0·2)																		

[1] Percentage crude protein in brackets.

of ammonia, apart from an exceptionally high value at the 4-cwt. level of application in May.

Crude protein percentages for the hay cuts are given in Table 8. The nitrogen-treatment averages for the 1946 and 1947 applications of fertilizer show that there was a decrease in the percentage crude protein with increasing rates of sulphate of ammonia. This was correlated with the depressing effect of nitrogen on the clovers and was accentuated by the exhausted condition of the ley. The crude-protein percentages from the plots fertilized in autumn and spring at 1 and 2 cwt. per acre differ very little. Four cwt. in the spring was somewhat more effective in maintaining the proportion of crude protein than 4 cwt. in the autumn.

Reference to the yields of crude protein from the hay cut (Table 8) shows that the nitrogen plots generally produced more crude protein than the controls, but differences between the rates of nitrogen are not consistent. In the autumn-manured plots it was the 2-cwt. applications that resulted in the largest yield of crude protein, but there were no differences between the dates of application. The differences in yield between the rates of application of fertilizer in the spring months were very slight. The largest production of crude protein resulted from applying the higher levels of nitrogen in May, again emphasizing the importance of late dressings of nitrogen upon the crude-protein content of the herbage.

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Summary

1. In the first silage cut, 1946, sulphate of ammonia at all rates of application raised the percentage of crude protein in the herbage. In subsequent cuts the crude-protein percentage was related to the proportion of clovers in the sward.

2. Applications of fertilizer made less than a month before cutting were the most effective in raising the percentage of crude protein.

3. Spring nitrogen, except when applied less than a month before cutting, was no more effective in raising the crude-protein percentage or in giving a greater production of crude protein than autumn nitrogen.

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IRON AND ZINC DEFICIENCIES IN CACAO IN THE GOLD COAST

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WITH PLATES 2 AND 3

CALCAREOUS soils are rare in the cacao-growing areas of the Gold Coast. With few exceptions the soils consist of a considerable depth of leached material of high acidity (pH 4·5 to 6·0) overlain by a shallow layer rendered fertile by the mineralization of leaf-litter. Within this surface-layer there is a steeply falling pH gradient, and it is unusual to find a pH exceeding 6·5 at depths greater than 6 in. Liming and manuring are not practised: the main danger of lime-induced deficiencies comes, therefore, from the wood-ash resulting from the burning of forest vegetation before the cacao is established.

Few cases of iron chlorosis are to be seen on peasant farms, in which cacao seed is planted directly in the field during or after 1 or 2 years of intensive food farming. But acute symptoms of iron deficiency have been observed when, following plantation practice, established seedlings have been transferred to planting-holes dug on land that has been burnt over; they have also arisen in seedlings grown from seed planted in potted soils containing compost prepared with the aid of wood-ash.

Zinc deficiency, which a series of experiments with water-cultures has established as the factor primarily responsible for sickle-leaf disease [1], has similarly proved much more prevalent in the nursery than in the field. In peasant farms it appears to be mainly confined to the vicinity of refuse-heaps and husk-dumps and is probably of little economic importance; it has, however, occurred frequently in seedling-beds made up with soils scraped from the surface beneath mature cacao-trees.

Since iron deficiency has on one occasion threatened the demise of a valuable collection of seedlings, and the disturbing mottle of zinc deficiency has more than once made an untimely appearance in potted plants in which it had been hoped to detect transmitted virus symptoms, it has been thought that an account of the conditions under which the two deficiencies have appeared in the Gold Coast may prove of interest to others engaged in the propagation of cacao.

Iron Deficiency

Occurrence

1. *Termite-mounds.*—A calcareous horizon is present below weathered (fossil ?) termite-mounds, which are of frequent occurrence in the forest area. Cacao planted at the summit of the mounds, where the

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calcareous zone is overlain by 3–4 ft. of acid clay, makes good growth. Mild symptoms of iron chlorosis are, however, occasionally apparent in mature trees planted near the base of the mounds, where the calcareous horizon lies close to the surface.

Acute symptoms leading to death were observed at Tafo, in 1941, in two plants budded on cacao stocks 4–5 ft. high. The stocks were growing near the base of a termite-mound that had obviously been disturbed during cultivation: nodules of calcium carbonate were scattered at the surface around the trees in a small patch where weed-growth was noticeably chlorotic. Budded cacao growing 3 yds. from the affected plants was normal. Soils from the top 12 in. near the affected trees had a pH of 7·8 and contained 1·5 per cent. calcium carbonate: soils to the same depth near neighbouring healthy trees had a pH of 6·6 to 6·8 and contained no carbonate.

2. *Wood-ash.*—(*a*) *Peasant farms.* Two factors may account for the comparative rarity of iron deficiency in cacao established by native practice. In the first place the intensive food farming that accompanies or precedes the planting of cacao is well calculated to disperse any accumulation of ash that may form during the burning of forest. Secondly the direct planting of seed not only avoids the re-accumulation of ash that may result when surface soil is scraped together to fill planting-holes for the accommodation of transplanted seedlings, but also permits the young seedling to face any dangers inherent in the alkaline soil surface whilst still drawing its nutrient supply from the cotyledons.

It is the Gold Coast practice to burn *in situ* the trunks of trees which have no value as timber and are too large to be removed for firewood. Chlorosis has been noticed on peasant farms in cacao growing close to decaying trunks that have been incompletely burned.

(*b*) *Planting-holes.*—The native practice of clearing and burning was followed in one of the early Methods of Establishment trials at Tafo. The trial also served as a test for the seedling progeny of selected trees, some of which were not ready for transplanting in the experiment area until many months after the clearing of the land in 1939.

In November 1940 acute chlorosis was found in one plot amongst year-old seedlings that had been moved to their planting-holes 2 months previously. The affected area was about 200 sq. yds. and contained at its centre 6 plants with ivory-white leaves; these were ringed by 8 plants with pale-green leaves. Outside this sharply defined area seedlings of similar history were growing normally. Diagnostic leaf-paintings showed that the chlorosis was due to iron deficiency and, as this was the first case to be encountered, leaves of individual trees were used for testing ferrous sprays of various strengths: experiments which were later to prove of value. No general treatment was given, however, and the affected plants ultimately died after developing symptoms of increasing severity. The presence of a large quantity of wood chips near the affected area pointed to the felling and burning of a large tree whose ash had apparently found its way into the planting-holes. Soils within the planting-holes of chlorotic trees had a pH of 7·7 to 7·9 and contained

from 0·68 to 1·6 per cent. calcium carbonate, whereas soils from the planting-holes of healthy trees had a pH of 6·8 to 6·9 and contained no carbonate in the surface 6 in.

(*c*) *Pots.*—The importation from Trinidad and South America of commercial types of cacao (*Theobroma cacao* L.) and of related species of Theobroma, from which it was hoped to breed strains of cacao resistant to swollen-shoot virus, called for their quarantine against the introduction of witches' broom disease (*Marasmius perniciosus* Stahel). A greenhouse for the potting of imported seed was therefore built in 1943 in the port of Accra, which lies in a dry zone 20 miles from the nearest cacao-growing area and 70 miles from the Tafo Research Station.

A decision to reduce transport costs by compounding in Accra a potting medium consisting of washed sea-sand, compost, and surface soil brought from Tafo, proved unfortunate owing to the alkalinity of the compost, which had been prepared by the Indore system with liberal incorporation of wood-ash. The presence in the sand of numerous fragments of hard shell was probably of less immediate detriment than the need to water plants, and to humidify the greenhouse during dry periods, with municipal water limed to pH 8·2.

When the seedling collection was seen in July 1944, acute iron deficiency was causing the death of a number of seedlings of Trinitario type that had been planted from November 1943 onwards, and there were distressing symptoms of chlorosis in later arrivals of other types. Samples of soil from individual pots contained from 5·4 to 8·4 per cent. calcium carbonate; their pH ranged from 7·7 to 8·3. Although an immediate change was made in the potting medium for the reception of further seed it was not practicable to repot the large number of delicate seedlings already planted, and it was necessary to nurse them with ferrous sprays through their 6 months' quarantine and their subsequent transfer to Tafo. Treatment was more successful than had been hoped, and it proved possible to transfer to the Tafo nurseries more than 90 per cent. of the original collection of 2,400 seedlings.

Symptoms

(*a*) *Young seedlings* (*Accra Quarantine*).—The progression of symptoms in *T. cacao* was essentially similar to but less rapid than that described for seedlings grown in water-cultures lacking iron [1]. Leaves formed prior to the shedding of the cotyledons were of normal colour and texture; when approaching senescence some developed a crenate marginal scorch apparently identical with that which Hardy [2] found associated with potassium deficiency.

Chlorosis was usually apparent in the first flush formed after the cotyledons had been shed. The earlier leaves of the flush were light green with a vein pattern sharply defined in normal green (Plate 2, fig. 1): succeeding leaves became progressively paler in colour. These pale-green leaves were retained by the plant for several months. After 2 months scorch appeared at the tip and gradually spread along the margins to the mid-point of the leaf, forming a rusty rim about 1 cm. wide. No further deterioration occurred in these leaves except a gradual

bleaching of the rusty rim. In subsequent flushes there was a continued decrease in pigmentation until leaves became pale cream with a light-green vein pattern (Plate 2, fig. 2). Tip-scorch developed on these leaves after about 1 month; the tip then began to curl, usually upwards, and scorch spread rapidly back to the mid-point of the leaf. The scorched portion then disintegrated (Plate 2, fig. 3) and the leaves were shed within 2 months of emergence.

The last leaves of the plant's final flush were ivory-white and of papery texture; they were usually hooked downwards at the tip and curved into the shape of an inverted boat. They developed scorch at the tip and at points along the margin soon after emergence and were retained by the plant for only 2 or 3 weeks. The terminal bud was then usually dead and the plants died, after sometimes producing an abortive shoot from one of the lowest leaf-axils.

T. balaoense (Herrania) and *T. microcarpum* developed symptoms similar to those described for *T. cacao*. Slightly different symptoms were, however, observed with *T. grandiflorum*. The leaves of this species, which are pubescent and claret coloured when newly emergent, developed marginal scorch that was deep russet in colour compared with the yellow-brown shades of scorched cacao. In severe cases symptoms were apparent in young leaves shortly after emergence: while still red or bronze-green they took the shape of an inverted boat and wilted from the tip inwards, the distal portion hanging flaccid for several days before showing signs of scorch.

The leaves of a few plants of cacao were distinguished by sharp dentations near the tip; the leaves were but mildly chlorotic and were slow to develop tip scorch [3]. Dentation has not been noticed in plants grown in water-cultures lacking only iron: it has, however, been produced in cultures lacking both iron and manganese and by raising the pH of a complete nutrient solution [1].

(*b*) *Year-old seedlings* (*Tafo, 1940*).—Leaf-symptoms were similar to those seen in potted seedlings. Whilst the leaves of any flush were more chlorotic than those of the preceding flush, there was no regular increase in the degree of chlorosis in the four or five individual leaves forming the flush: the second leaf might, for instance, be less chlorotic than either the first or third. Parti-coloured leaves, of a type later reproduced in cultures of high pH [1], were common. They showed a regular gradation of pigment passing from the base to the tip of one lamina and returning from the tip to the base of the other, i.e. colour contrast between the laminae was greatest near the petiole. Where plants produced a succession of parti-coloured leaves the pattern appeared to be determined by a factor passing vertically up the stem; the picture showed marked similarity, if green and white were reversed, to that produced by the injection of salts of iron through the petiole of an iron-deficient plant of $\frac{3}{8}$ phyllotaxy [4*a*].

On the death of the terminal bud most plants produced one or more axillary shoots, which formed a varying number of small chlorotic leaves before dying.

Treatment

1. *Sprays.*—The preliminary Tafo tests had shown that a 1 per cent. solution of ferrous sulphate (hydr.) caused no damage to cacao buds or young leaves, and brought improved colour to young leaves within 3 days and to mature leaves within 4 to 5 days of spraying. Sprays of this strength, with the addition of sufficient sulphuric acid to counteract the lime in the tap-water, were used in the treatment of the seedling collection in the Accra Quarantine Station. No spreader compatible with iron was available and a single spraying was found to produce a very spotted effect on mature leaves; a better cover was obtained with softer young leaves (Plate 2, figs. 1 and 2). It was also found that repeated spraying of stems and dormant leaf-buds had little or no effect on the foliage that emerged subsequently: spraying did, however, lead to the retention of all chlorotic leaves except those in which necrosis was already well advanced.

Three sprayings, at intervals of 2 days, were given as soon as possible after the formation of each flush of new growth. This treatment proved successful not only with cacao but also with *T. balaoense* and *T. microcarpum*. Hardened chlorotic leaves of *T. grandiflorum* also responded well, but spraying failed to arrest the development and spread of scorch in the flaccid tips of contorted young leaves. It was found necessary to repot plants with severe symptoms; snipping off the flaccid tips seemed to arrest the spread of scorch and to assist the plants' recovery.

2. *Soil treatment.*—Soil treatment proved a poor substitute for spraying, owing partly to the large number of shell fragments in the soil, and partly to the caution enjoined in handling such a valuable collection of plants. One of the more successful experiments was made with 16 treated pots and 16 untreated controls. Treatment consisted of 20 successive applications, at 2-day intervals, of 200 ml. of 0·25 per cent. sulphuric acid per pot (soil-content = 4 kg.), whereby the pH of the soils was reduced from 7·9—8·3 to 6·2—7·4; this was followed by 2 applications of 200 ml. of 0·25 per cent. ferrous sulphate–sulphuric acid. Two months after the final treatment the condition of the pots was:

	Untreated	*Acid and iron*
Dead	3	1
Acute chlorosis	1	0
Mild chlorosis	9	3
Normal	3	12
Total	16	16

Zinc Deficiency (Sickle-leaf)

Occurrence

The intensive search for leaf-mottle, which followed the discovery that swollen-shoot virus could be detected at an early stage by means of the mosaic present in young leaves, led in 1940 to the frequent finding of

mottled leaves that were often abnormally long and narrow or possessed a marked lateral curvature. The mottle was distinct from that of swollen-shoot virus, for the pattern was one of intervenal chlorosis, or vein shading, as opposed to the vein clearing and banding of virus mosaic [5].

The affection was first given the name 'sickle-leaf mosaic', but after attempts to transmit it by budding and grafting had proved unsuccessful [5] and good evidence had been obtained that it was soil-induced [6], the name was amended to 'sickle-leaf' in accordance with the wish of the Mycological Institute that the term mosaic be used only for virus infections.

Despite the marked difference in the leaf-patterns produced by the two diseases, specimens of sickle-leaf were repeatedly tendered by inexperienced surveyors as evidence of swollen-shoot disease, not only in the Gold Coast but in Nigeria and the Ivory Coast. Some confusion was perhaps pardonable on account of the frequency with which the mottle was found alongside true mosaic in the field. Sickle-leaf was found to be particularly prevalent amongst trees that received seepage from the mounds of rotting pod-husks, which arise where ripe pods are gathered for the extraction of the beans. Since ripe pods are collected over a wide area and are often infested with the mealy-bugs (Pseudococcus spp.) that transmit virus disease, the pod-heap is also a potent focus for virus infection.

The examination of soils carrying trees affected with sickle-leaf invariably showed that they had a high pH and an unusually high content of available phosphate and potash. The following samples were collected in September 1941 from farms in the Trans-Volta Division of the Gold Coast in which both virus and sickle-leaf were present, sometimes in the same tree.

TABLE 1. *Soils from Farms affected with Sickle-leaf and Cacao Virus*

Farm	*Symptoms*	*Depth in.*	*pH*	*Per cent.*		*p.p.m.*	
				C	*N*	P_2O_5	K_2O
Chameyi	Virus: no sickle-leaf	0–6	6·8	2·90	0·236	46	82
	Sickle-leaf: no virus	0–6	7·0	2·14	0·183	210	212
Peki Blengo	Virus: no sickle-leaf	0–12	6·5	1·03	0·081	14	45
	Sickle-leaf and virus	0–12	6·9	1·39	0·083	183	124

In mature trees symptoms of mottle have appeared temporarily in foliage developed during a period of drought, and one case has been reported where the condition was apparently induced by exposure consequent on the defoliation of neighbouring trees by capsid bugs. Similarly, when identical sets of affected seedlings have been kept under different conditions of moisture and shade, the most acute symptoms have been developed by plants given the greatest degree of exposure and the lowest supply of moisture.

Induction.—Following the discovery that sickle-leaf was often associated with husk-dumps it was found that the condition could be induced in normal seedlings by digging pieces of rotting husk into the

surface soil. Cacao-husk has a high potassium-content and the ash, which can also be used to induce symptoms, is a favourite material for the preparation of soap lyes; an infusion of rotted husk is alkaline.

Soil for potting cacao seedlings is often collected beneath mature cacao-trees. When collection consists of a surface scrape, which gathers a high proportion of decomposing (alkaline) leaf-litter, sickle-leaf often appears in young seedlings; it has also appeared with disconcerting frequency in the first and second leaf-flushes following the transfer of older seedlings to new pots for the study of virus transmission. In the second case, plants have usually suffered no set-back and the affected leaves have often been unusually large.

In Nigeria, where cacao-bean ash, available in some quantity as a result of the burning of unexportable cacao in 1940, had been recommended as a fertilizer for cacao, it was found that only small quantities of ash were needed for the immediate induction of symptoms. Experiments made at Tafo showed that with sandy surface soils (clay-content = 15 per cent.) an application of 4 gm. ash per kg. of soil was sufficient to induce persistent symptoms; a $\frac{1}{25}$ aqueous extract was found to be as effective as the entire ash. The extract is strongly alkaline and consists almost entirely of the carbonate, phosphate, and sulphate of potassium; part of the potassium and phosphate contained in the ash remains combined with calcium and magnesium in the insoluble residue.

Symptoms

Symptoms have been studied in seedlings of various ages potted in soils gathered beneath mature cacao trees and in year-old seedlings in which symptoms of increasing severity were induced by the addition of bean-ash in quantities ranging from 1 to 8 gm. per kg. of soil.

The first symptom appears as a bluish-green vein-banding in dark-green leaves of normal shape; the leaves are dull and leathery and normally persist unchanged. They may, when of advanced age, develop a succession of narrow wavy bands of marginal scorch similar to that observed during the senescence of the normal leaves formed in the flush which preceded the appearance of iron chlorosis in the Accra seedlings. In view of the similarity of this symptom to the marginal scorch found in Trinidad in plants lacking potassium [2], it is perhaps worth noting that this type of scorch has been noticed not only in plants receiving liberal applications of bean-ash but also in plants treated with potassium carbonate.

Succeeding leaves are of similar shape and colour, though slightly corrugated by the arching of the intervenal spaces into folds convex to the upper leaf-surface. At various periods, often several weeks, after the leaf has hardened, small chlorotic patches of primrose colour appear between the veinlets on the crests of the folds; the patches may be single, about 2 mm. in diameter, or disposed in a line along the crest. Sometimes only one or two of the intervenal spaces are affected: sometimes the whole leaf is covered by a mosaic pattern of attractive appearance. These mottled leaves are retained by the plant.

Leaves of the next growth-flush are usually deformed; the deformity

is of two types and is apparent in young leaves before they have reached a length of 1 cm. The first type is the lateral curvature that gave rise to the name sickle-leaf: in a mature leaf the ratio of the lengths of convex and concave margins may be as high as 4:3. In the second type the leaf is straight but attenuated, the ratio of length to breadth of a fully developed leaf reaching 7:1, compared with a ratio of 3:1 for a normal leaf. Narrowing starts some distance from the petiole so that the base of the leaf is 'waisted'; the tip is drawn into a long point which is often curled, and slight crenations may occur near the tip (Plate 3, fig. 1).

A certain amount of waviness, due to the uneven folding of the intervenal spaces, is found with both types. In a young leaf the veinlets are distorted and slightly raised from the leaf-surface (Plate 3, fig. 2). When elongation ceases pigment diffuses into the leaf to form a dark-green vein pattern raised above a light-green surface. As the leaf ages the pits between the veinlets become yellow, and transparent streaks frequently appear near the mid-rib. Leaves of this type remain on the plant. They are of normal size in the first affected flushes, but there is a marked reduction in leaf-size when symptoms persist through subsequent flushes.

The symptoms so far described are the only ones observed in nursery seedlings and in seedlings given moderate doses of bean-ash; after producing one to three flushes of distorted leaves they have usually formed normal foilage.

In plants receiving doses of bean-ash exceeding 4 gm. per kg. of soil there was a progressive degeneration in subsequent flushes. The degree of chlorosis became more pronounced, the whole leaf remaining a light yellowish-green. Soon after the leaf had hardened, elliptical necrotic patches appeared in the intervenal spaces (Plate 3, fig. 1); the tip became scorched and the leaf was shed. The terminal bud then died and a succession of small yellow-green lanceolate leaves, gradually decreasing in length from about 7 cm. downwards, was produced on spindly secondary shoots. These leaves were quickly shed; the shoots withered and the plants died.

Symptoms of this order of severity have not been noticed on Gold Coast farms. They have, however, been fully described by Ciferri for mature trees affected with 'narrow dented leaf' in South America (*v.* page 82).

Diagnosis

1. *Intervenal injections.*—Although leaf-symptoms and the manner of their induction were strongly suggestive of trace-element deficiency, a preliminary series of intervenal injections, made by Roach's method [4*b*] with salts of magnesium, calcium, iron, manganese, zinc, and boron, showed response only in the case of iron (0·025 per cent. ferrous sulphate plus sulphuric acid).

Hardened leaves made no response to half-leaf paintings with 1 per cent. ferrous sulphate, but fairly consistent success was obtained on young leaves treated just before changing from bronze to green. Unlike

the effect produced on iron-deficient leaves, which develop pigment wherever the leaf is touched by the iron solution (Plate 3, fig. 1), increased pigmentation was confined to the neighbourhood of the veins and was most prominent near the mid-rib in the treated half of the leaf; the effect was often not apparent until 10 days after treatment. There was, however, over-all response to paintings of 1 per cent. ferrous sulphate by the yellow-green lanceolate leaves formed in the final flushes of plants receiving heavy doses of bean-ash.

2. *Water-cultures.*—Since no published account of trace-element deficiency in cacao could be found, it was thought advisable to attempt quick definitions of leaf-symptoms by the use of water-cultures. Accordingly, between April 1945 and November 1946 seedlings grown in washed sand and distilled water were, shortly after the shedding of the cotyledons, transferred to nutrient solutions lacking (1) iron, (2) manganese, (3) boron, (4) calcium, (5) magnesium, (6) zinc, (7) iron-manganese, (8) iron-zinc, and (9) zinc-manganese. Seedlings were also grown in complete nutrient solutions containing iron in quantities ranging from 0·1 to 1·0 p.p.m. Fe, and in complete solutions maintained at pH values ranging from 6·0 to 6·8. Well-defined symptoms were obtained in all cases except that of minus magnesium, where rapid defoliation occurred in the only two flushes formed in culture [1].

Sets of four seedlings were on two occasions grown in cultures lacking *zinc only*. In the first set (July 1945–July 1946) all plants developed the primrose-and-green mottle characteristic of the early symptoms of sickle-leaf in the first and second flushes formed in culture; lateral curvature and a distorted vein pattern were observed in the last leaf of the second flush of two plants. Good examples of highly curved and of straight, elongated leaves, which on ageing developed the raised-vein pattern and mottle of sickle-leaf, were formed in the fourth to the eighth flushes of all plants.

In the second set (April–November 1946) mottling occurred in the leaves of the first flush of only one plant; it was present in the second flush of all plants. Typical sickle-leaves, both curved and straight, were common in the fourth and fifth flushes of all plants.

Neither set of plants showed the progressive degeneration observed in plants treated with bean-ash: there were, in fact, a number of apparently normal leaves in almost every flush. It seems probable that this was because no attempt was made to remove traces of zinc from the water and reagents used in making the nutrient solutions; it is noteworthy that these two sets of plants were the only ones of the series in which growth was not significantly less than in complete nutrient.

In cultures lacking both *zinc and manganese*, mottle appeared in the second flush; typical sickle-leaves were frequently produced in the fifth and sixth flushes.

No mottle was present in plants grown in cultures lacking both *zinc and iron*: leaves were whitish-green with dark-green banding alongside the veins. One plant in its first flush and 2 plants in their third flush formed curved leaves with raised distorted veins. All 4 plants produced this type of leaf in their fourth flush. Of a total of 17 leaves only 4 were

of normal shape: 11 were highly curved and 4 were abnormally long and thin; on ageing they developed elliptical necrotic patches in the intervenal spaces. Small highly-curved thin leaves, which were rapidly shed, were formed in a succeeding flush.

No other treatment gave rise to symptoms suggestive of sickle-leaf except a *complete nutrient* solution maintained at pH 6·8. Of three plants used in this treatment one produced two sickle-shaped chlorotic leaves in its first and only flush; a second formed two similar leaves in its third and final flush. Plants maintained at pH 6·0 were normal, but varying signs of iron and manganese deficiency, including irregular dentation, appeared in plants maintained at pH's of 6·2, 6·4, and 6·6.

It seems safe to conclude, therefore, that zinc deficiency is responsible for the symptoms of sickle-leaf normally encountered, and that lack of iron may assist in the production of the more acute symptoms observed in plants treated with heavy dosages of bean-ash.

3. *Leaf-paintings.*—Early intervenal injections with zinc were made with 0·025 per cent. zinc sulphate–sulphuric acid, which produced no effect except necrosis around the puncture. When it was found that sickle-leaves were regularly produced in cultures lacking zinc, a fresh series of injections was carried out, using acidified zinc sulphate of reduced strength. A number of clear responses were made by young leaves injected with 0·01 per cent. zinc sulphate–sulphuric acid, and two petiole injections with the same solution proved highly successful: a well-defined pigment pattern was produced in the foliage emergent from buds that were dormant at the time of injection.

No success whatever has attended numerous paintings of mature, curved leaves with zinc sulphate solutions of various strengths. Response has, however, been shown by soft young leaves painted with 0·5 per cent. hydrated zinc sulphate solution shortly after losing their bronze tint. A light-green colour, sometimes detectable with difficulty on account of its tendency to diffuse throughout the lamina, appears about 8 days after treatment (Plate 3, figs. 2 and 3).

Much more consistent success has been obtained by painting soft young leaves with a solution containing 0·5 per cent. hydrated ferrous sulphate, 0·33 per cent. hydrated zinc sulphate, and 0·05 per cent. sulphuric acid. In controlled experiments in which the mixture was tested against each of the ingredients, the mixture was found to produce a much darker green than either zinc or iron alone; the effect was also visible earlier, usually in 4 to 6 days from the time of treatment.

Narrow Dented Leaf in South America

It was not until the series of water-cultures here described was nearing completion that it was discovered that Ciferri had in 1929 [7] described an affection of cacao which he had found in the Dominican Republic and had tentatively labelled 'debida a un virus' [8]. His detailed description of symptoms and the excellent series of photographs accompanying his article leave no doubt that this affection is identical with sickle-leaf.

In a private communication dated February 1949, Dr. Ciferri has drawn the writers' attention to a second publication (1948) which

recapitulates his early work, includes further observations made in the Dominican Republic between 1930 and 1932, and records the discovery of the same disease in the Cauca valley of Colombia [8].

In his first article Ciferri lays stress on the failure of a large number of attempts to transmit the disease by the injection of extracts of ground diseased leaves into petiole and main vein, and by grafting affected shoots on to unaffected stocks. But in his second article he accepts the results of a series of grafts made in 1929 on year-old seedlings (4 possible transmissions out of 31 grafts) as proof of its sap-transmissibility: his article is entitled 'Una Virosis del Cacao' and its main purpose is to emphasize the difference between the symptoms of his 'virosis' and those described by Posnette [9, 10] for virus affections of cacao in Trinidad and Venezuela. He proposes the name 'narrow dented leaf virus' for the affection which we have here called sickle-leaf.

In his private communication Dr. Ciferri makes it clear that he entertains some doubt whether 'narrow dented leaf' is a true virus, and that he has had no access to the full text of the first widely published note which explained the essential differences between sickle-leaf and swollen-shoot virus [5]. It has been suggested to him that an examination of the soils supporting normal and affected trees would prove worth while.

Ciferri's painstaking description of symptoms is the more valuable in that it relates to mature bearing trees. He lists every symptom here described for seedlings, including those observed in plants given a heavy dosage of bean-ash. Thus he records that the appearance of uniformly chlorotic leaves is followed by the production of some secondary shoots which wither after developing rosettes of small leaves; further growth is then limited to small patches of leaves on the older branches. He also records that fruit production ceases once the tree has begun to produce attenuated or curved leaves; flowers are formed, but either they fail to set or the cherelles shrivel and drop.

He notes that in the Dominican Republic the disease appeared to be mainly confined to two small areas near Santiago, and that although he was assured by local farmers that the disease was infectious he found its distribution very irregular and its incidence slight. Thus he was able to find only 34 cases in an area of 20 hectares, with an estimated tree population of 12,000. Continuous records carried out on one farm showed that spread is slow and the mortality rate very low. Tree counts were:

Year	*1926*	*1927*	*1928*	*1929*	*1930*	*1931*	*1932*
Number diseased .	5	6	5	7	7	?	9
Number dead . .	?	2	4	2	0	?	1

He concludes that the disease is probably of little economic importance.

Iron-Zinc Deficiency

Seedlings grown in cultures lacking both zinc and iron, and in complete nutrient maintained at pH 6·8, produced leaves with the curvature

of zinc deficiency and the pale-green to ivory-white colour of iron deficiency. Mixed symptoms of this sort have not normally been encountered in seedling collections; the symptoms have been solely sickle-leaf or solely iron chlorosis, according to the potting medium used. There is, however, one instance of mass induction of symptoms of iron deficiency in plants already showing signs of zinc deficiency.

During a water-shortage at Tafo in March 1945 an attempt to reduce consumption was made by fitting plant-pots with drip-trays from which the percolate was returned to the pots at the next watering. It happened that of a collection of 60 potted cacao seedlings, about 2 ft. in height, all of which had in their last flush shown uniform incidence of sickle-leaf, 37 pots were fitted with drip-trays, 23 were allowed to drain freely.

The freely-drained plants quickly produced normal foliage: no case of sickle-leaf was apparent at the end of 3 months. The drip-tray plants formed new leaves which showed either: (1) sickle-leaf with typical mottle; or (2) large crescent-shaped leaves, ivory-white, giving ready response to ferrous sprays, or (3) ivory-white leaves of normal shape also responding to treatment with iron. Only 12 of the 37 plants were producing normal foliage at the end of 3 months.

This rather startling change would appear to have resulted from the recirculation of soluble material present in the percolate, which was, unfortunately, not examined. There was no suggestion that the moisture-content of the soil in the pots fitted with trays was approaching field capacity, a condition which had been found to exaggerate symptoms of iron deficiency in the Accra seedlings.

Discussion

The finding out that sickle-leaf was due to zinc deficiency gave added interest to experiments that had been made in 1944 to study its ready induction by an aqueous extract of bean-ash. Ash-extract is mainly composed of potassium carbonate and phosphate; it is highly alkaline and precipates both calcium and magnesium. Three factors may therefore contribute to its capacity to induce sickle-leaf: (i) its high pH, (ii) its high phosphate-content, (iii) its high potassium-content, possibly coupled with its ability to immobilize calcium and magnesium.

All three factors have been cited as promoting zinc deficiency. Camp [11] has summarized a number of cases in which the uptake of zinc by various plants has been gradually depressed by a progressive increase in the pH of the soil, whilst West [12] has recorded that in Australia zinc deficiency in citrus (foliocellosis) can be induced by phosphatic fertilizers, and that the addition of potassium intensifies the symptoms.

An attempt to decide which factors were dominant in the induction of sickle-leaf was made in pot experiments in which applications of (i) potassium carbonate, (ii) potassium carbonate plus potassium phosphate, were made in amounts roughly corresponding to the soluble material in an application of 8 gm. ash per kg. soil. Equivalent weights of (iv) sodium carbonate, (v) sodium carbonate+sodium phosphate, were used in parallel treatments, which also included (iii) a neutral potassium salt (sulphate), in excess of the total potassium-content of the soluble ash,

(vi) an equivalent weight of sodium sulphate, and (vii) an untreated control. Quantities were based on the analysis of a bulk sample of ash, which contained the following soluble constituents: $K_2O = 22{\cdot}02$; $Na_2O = 1{\cdot}84$; $CO_2 = 7{\cdot}10$; $P_2O_5 = 4{\cdot}09$; $SO_3 = 2{\cdot}93$; $Cl = 0{\cdot}12$; Total = 38·1 per cent.

Seedlings 6 months old were potted in an average 6 in. surface soil with a pH of 6·8. Four replicates of each treatment were used. They were kept under observation for 6 months, when all plants given potassium carbonate and potassium carbonate plus phosphate were producing normal foliage after having developed in their first two or three flushes typical symptoms of sickle-leaf and having maintained a growth-rate equal to that of the controls. Sickle-leaf had also been apparent in the first flush of two plants and in the second flush of one plant receiving potassium sulphate; this treatment had led to depressed growth.

Plants in the sodium treatments were also stunted. Their early foliage was bluish-green and later leaves were yellowish-green. The characteristic leaf-mottle or deformation of sickle-leaf appeared in the first flush of only one plant of each treatment. One plant treated with sodium sulphate and three plants treated with sodium carbonate plus phosphate died after producing only two flushes. The data are summarized below.

TABLE 2. *Induction of Sickle-leaf by Salts of Potassium and Sodium*

Treatment	*Number of plants*		*Number of flushes*	
Amount per kg. soil	*With sickle-leaf*	*Killed*	*Total*	*With sickle-leaf*
(i) K_2CO_3 1·25 gm.	4	0	16	9
(ii) K_2CO_3 1·25 gm.: K_2HPO_4 1·0 gm.	4	0	14	8
(iii) K_2SO_4 4·0 gm.	2	0	10	3
Total	10	0	40	20
(iv) Na_2CO_3 1·0 gm.	1	0	13	1
(v) Na_2CO_3 1·0 gm.: Na_2HPO_4 0·8 gm.	1	3	10	1
(vi) Na_2SO_4 3·3 gm.	1	1	10	1
Total	3	4	33	3
(vii) No treatment	0	0	15	0

The data show that the potassium treatments were much more successful than the sodium treatments in inducing recognizable symptoms of sickle-leaf, and that potassium carbonate was as effective as the carbonate-phosphate mixture. The relative ineffectiveness of potassium sulphate suggests that potassium salts can promote the induction only in soils with a pH above a critical value. The present experiment gave no help in finding this value as post-treatment pH values were measured by a glass-electrode subsequently found to be faulty; there appeared to have been a rise in pH from 6·8 to 7·4 in the controls and from 6·8 to 8·4 in the potassium sulphate treatment. Beyond showing that symptoms do not arise when extracts below pH 7·0 are used, a further attempt to decide the critical value by using bean-ash extracts treated with varying

amounts of sulphuric acid gave no useful information. It can only be stated that in well-watered potted plants no case of sickle-leaf has yet been found in soils with a pH below 7·5, and that the lowest pH determined for field soils carrying mature trees showing sickle-leaf in times of drought is 6·9 for the top 12 in.

In the hope of obtaining further insight into the effect of potassium concentration on the incidence of sickle-leaf it was planned to use two potassium levels, 50 p.p.m. and 250 p.p.m. (Ca = 156 p.p.m.) throughout the complete series of water-cultures here described. It proved possible to use differential potassium levels only with the first three elements studied (Fe, Mn, B): work had to be discontinued before similar treatment could be applied to cultures lacking zinc. An investigation of the effect of varying potassium/calcium ratios on cacao grown in cultures containing limiting amounts of zinc would appear to promise results of interest. In the cultures lacking iron it was found that the higher potassium/calcium ratio reduced the severity of symptoms of iron deficiency, and it seems not improbable that the K/Ca ratio may decide whether in soils of high pH the dominant symptoms shall be those of iron or of zinc deficiency.

Acknowledgements

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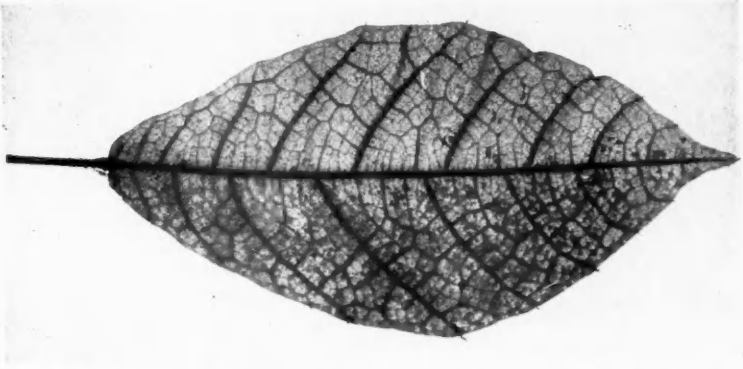

FIG. 1. Mild chlorosis. Right half given single spray with 1% ferrous sulphate when leaf mature. (*Theobroma balaoense*)

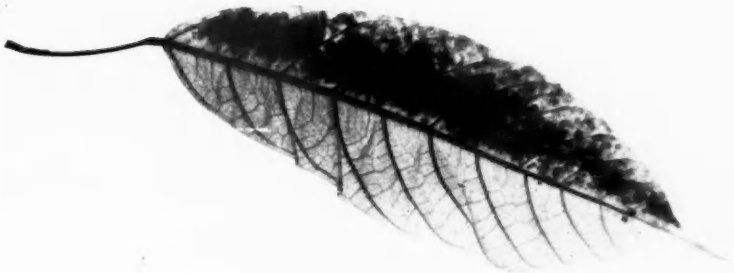

FIG. 2. Acute chlorosis. Left half given single spray with 1% ferrous sulphate when leaf young. (*T. cacao*)

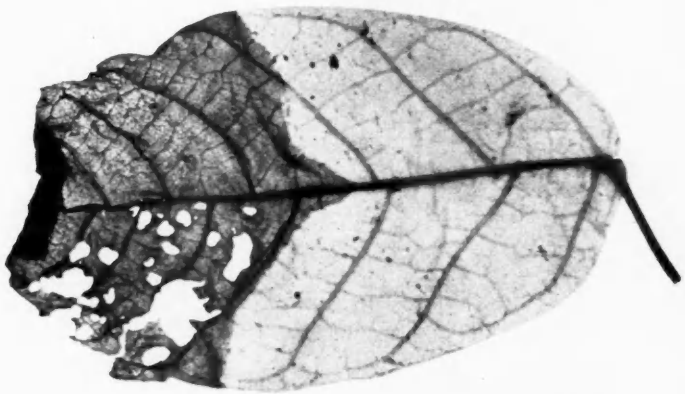

FIG. 3. Acute chlorosis, necrosis following tip scorch and roll

IRON DEFICIENCY

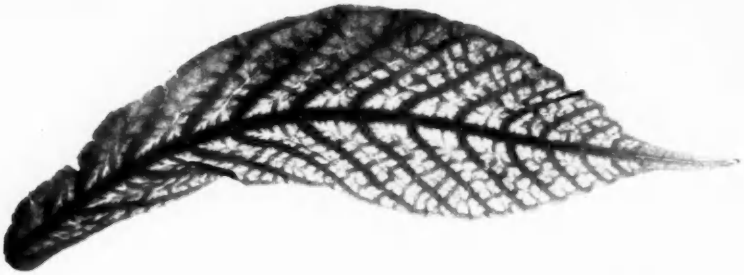

FIG. 1. Typical mature sickle-leaf showing curvature. Mottle and transparent streaks near mid-rib

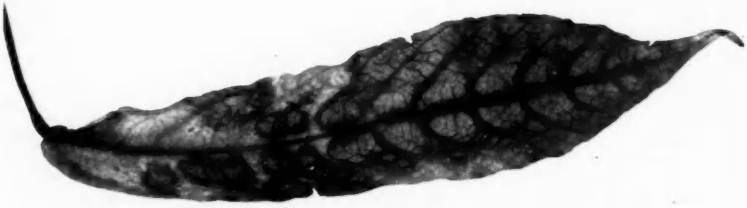

FIG. 2. Elongated leaf with acute chlorosis and intervenal scorch induced by bean-ash

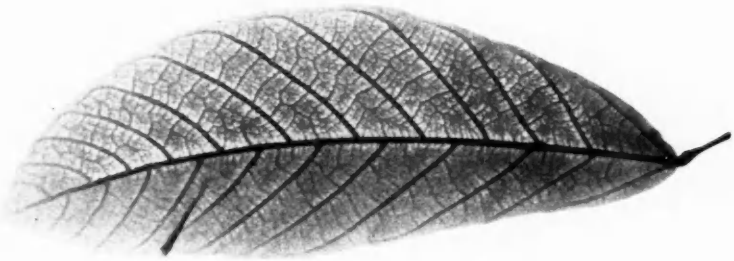

FIG. 3. Young sickle-leaf showing raised veinlets. Left side painted with zinc sulphate

ZINC DEFICIENCY

POTATO-BREEDING INVESTIGATIONS IN INDIA

B. P. PAL[1] AND PUSHKARNATH[2]

WITH PLATES 4 AND 5

Introduction.—The first mention of the potato in India, according to Watt [1], occurs in Terry's account of the banquet at Ajmer given by Asaph Chan to Sir Thomas Roe in 1615. As Ajmer is in the interior of the country, the potato must have been introduced earlier. In the beginning it was evidently cultivated only in a few small areas close to European settlements. Today the potato is cultivated to a greater or less extent in all parts of India, both in the plains and in the mountains where it is grown on terraces, some of which slope perilously. The total area under cultivation of this crop is, however, only about 500,000 acres, representing a small fraction of the net area under cultivation in India. This, at first sight, is surprising, for the potato is now generally considered a most acceptable article in the Indian diet, and many delicious forms of serving it, some of them unknown or uncommon in other countries, have been evolved.

Three reasons appear chiefly to have militated against the more extensive use of the potato in the agriculture of the country. First, about 90 per cent. of the potatoes grown in India are raised in the plains under short-day conditions in winter, the summer being too severe for the satisfactory growth of the crop. Varieties suitable for such conditions have not so far been available, India having depended upon foreign varieties bred for growing in summer, i.e. under long-day conditions, in their country of origin. Some of these varieties have proved suitable for the Indian hills where potatoes are grown in summer, and, in fact, the crop in the hills includes mainly the well-known European varieties Up-to-Date, Magnum Bonum, Great Scot (in the Nilgiri Hills in south India), &c.

The second important cause for the restricted cultivation of potatoes appears to be the enormous losses sustained during storage of the plains crop in summer, when high temperatures prevail and storage rots and the potato-moth work havoc, with the result that the prices of seed potatoes at planting-time may easily be twenty times those prevailing soon after harvest. There is evidence that cold storage of the harvested tubers overcomes the difficulty very satisfactorily. Cold stores dealing principally with potatoes are springing up in the main potato-growing area which is situated in the Gangetic plain, Uttar Pradesh and Bihar being the largest potato-growing states, and there is therefore reason to believe that with the provision of this facility, potato production will increase.

The third major cause for the lack of extension of potato cultivation has been the lack of expeditious transport that would enable potatoes to be moved from the areas where owing to irrigation facilities, &c.,

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potato cultivation is concentrated, to other areas where potato cultivation is not economic or practicable but where there would be a ready market for this tuber if regular cheap supplies were forthcoming.

Yet another factor of moment has been the lack of any organization for producing and distributing certified, reasonably disease-free, seed.

Considering that the potato is a valuable source of food energy which has become wellnigh indispensable in the agricultural system of Europe and America, and considering the high yields per acre which can be obtained relatively to the cereals and pulses, there is no doubt that India, faced with food shortage and a rapidly expanding population, requires to exploit the potentialities of this crop both by increasing its area and by taking measures to step up the rate of yield. The present average yield of 110 maunds (= 9,020 lb.) per acre is low, and with the evolution of varieties adapted to Indian conditions and by suitable manuring and cultivation, there should be no difficulty in raising the production of tubers per unit area. In fact there have been a few instances, e.g. in the Meerut area, where individuals for purposes of competition have raised crops yielding over 600 mds. per acre.

Earlier work.—Up to about 15 years ago, potato-improvement work in India consisted of the occasional importation and trials of the more important varieties from abroad, some manurial experiments, and the study of control measures against certain diseases and pests of the crop. Little actual breeding-work had been carried out; sporadic attempts had been made to raise new varieties from seeds, but apparently these did not lead to any successes. When therefore the Indian Agricultural Research Institute began breeding-work on potatoes in 1935, it started with a clean slate. This work was mainly conducted at Simla (for reasons explained below) where a branch station was set up under a scheme financed by the Indian Council of Agricultural Research.

Site of the breeding-station.—With a few exceptions, potato varieties rarely flower or form berries on the plains of India. It became obvious, therefore, that the breeding-station would have to be located in the hills. An experiment was carried out in 1935 to determine the most suitable location in the hills of northern India for such a station; a set of 20 varieties was studied at Murree, Katrain, Manali, Simla, Chaubattia, Khabrar, and Shillong, with the co-operation of the agricultural departments of the states concerned. Simla was finally chosen because flowering and berry formation proved satisfactory in most varieties, and it also possessed other facilities desirable for an experiment station (Plate 4, fig. 1). Besides laboratories and fields for experimental work, the Simla Station is equipped with glass-houses and controlled illumination chambers, the latter being intended for the maintenance of short-day species [2, 3].

The present paper sets forth briefly the results of work on potatoes conducted under the aegis of the Indian Agricultural Research Institute and its branch stations at Simla and Pusa during the period 1935 to 1949. Besides unpublished material, some of the published results are also mentioned with the aim of giving a connected account of the investigations.

Potato Collections

(1) *Indian potato varieties.*—An adequate collection of existing varieties is an indispensable requisite in modern crop-breeding. When the work began such a collection was not available in the country. The first step taken by the Indian Agricultural Research Institute was therefore to endeavour to build up a complete collection of Indian varieties and to collect information regarding them. Material was obtained partly by actual collection by the staff of the Institute and the Simla Substation and partly through the Directors of Agriculture of the various states. This material, comprising over 500 samples, was studied at Pusa (later Delhi, on the transfer of the Indian Agricultural Research Institute to the latter place) and also at Simla.

The results of the study proved that great confusion existed regarding the varieties of potatoes grown in the country and the area under each. The varieties were commonly designated by local names, usually descriptive of a typical character of the variety or of the place from which the seed originally came; these names often varied considerably from region to region, the same variety could be found under different names in different localities and sometimes several varieties were concealed under the same name [4, 5]. Ultimately it was possible to identify and eliminate many of the synonymous stocks and to group the remainder into a comparatively small number of varieties. In this connexion valuable service was rendered by the National Institute of Agricultural Botany, through Dr. R. N. Salaman, and the Potato Synonym Committee of which he was then the chairman, in the identification of samples. The results of this study are summarized in a bulletin now in the press [6].

The value of the South and Central American potato species and varieties for breeding-work is well known. Besides the materials collected in India, steps were taken for obtaining those available in other countries which had sent special expeditions to the original home of the potato species in South and Central America, and we are grateful to Dr. Hudson of the Commonwealth Bureau of Plant Breeding and Genetics who helped us to secure this material. Some material was also selected and brought from Cambridge from the Commonwealth Potato Collection (India having been a contributing country to the Empire Potato Expedition) by Dr. Pushkarnath, the Superintendent of the Simla Station, who was deputed for this purpose. The material collected and maintained at Simla (besides the collection made in India) consists of:

(2) *Foreign commercial varieties*, including known European and American varieties. This material was studied with a view to (*a*) determining if any of the varieties could be directly utilized for cultivation in India, and (*b*) discovering material likely to be of breeding-value. This collection contains some very important material especially suited for breeding potatoes resistant to late blight and virus diseases. In addition some of the stocks possess other desirable economic attributes like good shape and size of tubers, earliness, and fertility of pollen.

(3) S. tuberosum *varieties from Chile*. This collection represents material obtained from Dr. Schick of Germany, and also some from the

Department of Agriculture, U.S.A., and the Imperial Bureau of Plant Breeding and Genetics, Cambridge. Most of this material was, however, very badly infected with virus diseases and was either lost or had to be rejected. A total of about 170 varieties is now available. It is unlikely that in this collection any material of great breeding-value will be found.

(4) *Collection of* S. andigenum. Material from German, Russian, and Commonwealth sources is represented in this collection. From about 350 samples originally received, after elimination of duplicates and of stocks severely infected with virus diseases, about 80 distinct varieties have been established and are being maintained.

(5) *Collection of wild and cultivated tuber-bearing species of Solanum.* About 50 species, each sometimes represented by more than one variety, are available. Many of these, being short-day-adapted potatoes [7], fail to form good tubers under the long summer days in the hills. On the other hand, in the plains of India most of the species set tubers, but their vegetative vigour is greatly reduced and they frequently fail to flower. For breeding-work the collection is being grown at Simla and maintained under a 9-hour day in controlled illumination chambers.

As regards disease-resistance, no thorough investigation in respect of virus diseases has yet been made. Early-blight resistance is lacking in most of the species, but some species like *S. demissum*, *S. Antipoviczii*, *S. ajuscoense*, and *S. polyadenium* have been found to be immune to late blight both under natural field and laboratory conditions. *S. Antipoviczii* and *S. demissum*, both of which cross with *S. tuberosum*, have been utilized for breeding late-blight resistant potatoes.

(6) *Collection of exotic interspecific hybrids.* About 150 interspecific hybrids were secured from various sources, mostly Russia and the United Kingdom. Many failed to develop and only about 80 of these are now available. In the Russian material some valuable Demissum hybrids resistant to late blight were found and used for breeding blight-resistant potatoes. No useful degree of resistance to early blight or viruses was found in this material.

Potato-breeding

Problems.—The main problems of potato-breeding in India have been stated in earlier publications [8, 9]. Besides the objectives of high yield and good eating and keeping qualities, which are common to all areas, the short-day conditions under which potatoes are grown over the greater part of the potato-growing area constitute a special problem. Diseases are also important, especially those caused by the virus diseases. Whilst preliminary work [10, 11] has indicated that the most destructive virus diseases are similar to those in other major potato-growing countries, the viruses concerned being X, Y, A, and leaf-roll, the position in India is worse in that no systematic arrangements exist for the supply of certified disease-free seed. Since potato varieties rapidly degenerate in the plains, potato-growers in some areas are obliged periodically to renew seed from the hills where the incidence of the major virus diseases is lower. This, however, is not always practicable as the crop harvested at the higher altitudes cannot always be used for planting in the plains,

the interval between harvesting in the hills and planting of the first crop in the plains being too short to permit the completion of the normal dormancy period of the tuber. Late blight is common in the hills of northern India, and early blight in both the hills and plains; occasional outbreaks of late blight have also been reported from the plains. Wilt diseases and ring disease also cause much loss. Reference has already been made to the losses suffered during the storage period. Amongst insect pests, cutworms (Agrotis spp.), the Epilachna beetle, and the potato tuber moth (*Gnorimoschema operculella*) are the most important; the caterpillars of the last named not only damage the tubers during storage, but the tunnels made by them facilitate the entry of rot-producing fungi and bacteria and cause heavy losses. This particular problem will, however, find a relatively easy and inexpensive solution when adequate numbers of cold stores are built.

Damage by frost is not uncommon in northern India and constitutes another problem for the breeder.

Short-term project.—Work done abroad indicates that most of the problems just enumerated are capable of solution, as the requisite genes exist either in the cultivated or wild varieties. Projects involving the latter and some of the former have, for obvious reasons, to be considered as long-term investigations. Side by side with work on this type of problem, work was started at Simla to meet the immediate needs of the country for suitable varieties adapted to the varying conditions of soil and climate prevailing in the different parts of the country.

With this object in view, crosses were made between the most widely grown indigenous or *desi* varieties and some of the best commercial varieties from Europe and America. The study of Indian commercial potatoes revealed that there existed no indigenous *desi* stock approaching the modern standard, either as regards yield or quality of tubers. The so-called old *desi* potatoes have certain common features reminiscent of the semi-wild characteristics of certain South American potatoes. Thus the three oldest and the most commonly grown potatees, Phulwa, Darjeeling Red Round, and Gola, are all characterized by extreme lateness in the case of the first two, erect growth-habit, small foliage, numerous small deep-eyed tubers, long and scattered stolons, and a spreading fibrous root-system. Besides these undesirable features, the virus-riddled stocks of these *desi* varieties have completely degenerated. Seedlings raised from seeds of Phulwa and one or two other varieties proved disappointing. Introduction of improved foreign types or breeding of new varieties were thus the only two possibilities of improving the potato crop in India.

The modern commercial potatoes being bred to suit long-day environment were not considered to be particularly useful material for direct cultivation under short-day environment in the plains of India. Introduction of old commercial potatoes, now no longer grown in Europe, was considered to be a promising line of pursuit, for in this material it was likely that varieties adapted to short-day environment may be found. Crosses with such varieties would considerably increase the variability in the population and thus enhance the chances of selection of varieties

adapted to short-day environment. With this view in mind a large collection of old and new European potatoes was secured by Dr. Pushkarnath through the courtesy of several agricultural botanists in the United Kingdom.[1]

From a large series of crosses between *desi* and available European and American potatoes, numerous hybrid progenies were grown. From over 50,000 seedlings thus raised, after preliminary selection, about 5,000 were studied in some detail. A series of trials with a selected set of hybrids was carried out at several hill stations throughout India in Assam, Baluchistan (now included in Pakistan), Bengal, Bombay, Kashmir, Madras, North-West Frontier Province (now in Pakistan), Punjab, and Uttar Pradesh with the co-operation of the agricultural departments of the states mentioned, for 7 years. Although statistically significant results could not be achieved at several centres owing to soil heterogeneity and other difficulties, Hybrids Nos. 2, 5, 9, 12, 13, and 19 have emerged as varieties adapted for the hills of India. The salient characteristics of these varieties are shown in Table 1.

TABLE 1. *Summary of Average Yields (1942–8) per 100 Plants in Trials of Potato Hybrids*

Province	*Site of trial*	*Yield in lb. for hybrid nos.*							*Remarks*
		2	*5*	*9*	*12*	*13*	*19*	*Local*	
Kashmir .	Srinagar	83·6	105·7	..	..	..	46·6	45·2	Hybrid 2 is very susceptible to mosaic.
E. Punjab	Manali	..	..	86·8	77·3	..	80·0	77·3	Hybrid 5 does not store well.
Uttar Pradesh	Bhowali	..	75·4	89·8	89·3	..	..	73·3	Hybrid Nos. 9 and 12 are very tolerant of viruses and show very little infection.
Assam . .	Shillong	81·5	75·1	70·0	..	..	..	65·0	
Bengal . .	Darjeeling	..	37·9	37·3	32·3	35·8	25·0	23·1	
Madras .	Nanjanad	..	..	..	..	54·5	..	45·0	Hybrid 13 shows some resistance to early and late blights.

In addition to the hybrids, a few of the best imported varieties, viz. Up-to-Date, Ekishirazu, Imperia, President, Craig's Defiance, &c., were also included in the trials. The results indicated that Craig's Defiance was a good variety for Bombay and in certain hill regions, especially Simla hills.

It is necessary to explain why results were available earlier for the hill regions, whereas the main problem is that of varieties for the plains. Although theoretically the ideal procedure would be to sow the crossed seeds in the plains and thus select out directly those seedlings which

[1] For the help rendered to us we are particularly grateful to Mrs. McDermott, Midland Agricultural College, Sutton Bonnington, Loughborough; Mr. Findlay, North of Scotland College of Agriculture, Aberdeen; Mr. Bankhead, Department of Agriculture, Irish Free State, Dublin; and Mr. Clarke, Broughgammon, Ballycastle, Northern Ireland. Apart from the commercial types, Mr. Clarke was very generous in making available some of his own breeding-stocks and a number of crosses as seed.

Disease-free stocks of European commercial varieties were very kindly given by Dr. K. M. Smith, Director, Plant Virus Station, Cambridge. These are being maintained under glass-house conditions at Simla.

perform well under the local conditions, experience soon showed that the incidence of virus diseases in the plains was so high that almost all seedlings were severely infected, and often a plant that appeared promising in the first year passed into oblivion the very next year. Therefore the crosses were made and grown at Simla in the first year, and after a preliminary selection in which only types with grossly undesirable attributes such as irregular shape and very deep eyes were eliminated (in order to preserve as many genotypes as possible for trial under plains conditions), the tubers were brought down and studied in the plots of the Botany Division of the Indian Agricultural Research Institute and its Botanical Substation, at Pusa in Bihar. Owing, however, to the dormancy difficulty already alluded to (artificial methods of breaking dormancy resulted in an appreciable amount of mortality), these studies in the plains could not be undertaken on the scale required until a small substation at Bhowali was established in 1941; as this was situated at an intermediate elevation with a potato-growing season earlier in the year than the high altitudes, the difficulty about dormancy of tubers was conveniently 'bridged' over.

From the material studied at Delhi (Mr. M. J. Deshmukh of the Indian Agricultural Research Institute was associated with the writers in this) Hybrids Nos. 45, 208, 209, and 610 have been provisionally selected. The salient features of these varieties are summarized in Table 2. In trials conducted at Delhi and the Karnal Substation of the Indian Agricultural Research Institute and at two centres each in Bihar and Uttar Pradesh with the co-operation of the Economic Botanists concerned, these have proved to be high yielding and early, and they have tubers of better size and shape than the *desi* varieties; they are also tolerant to virus diseases.

TABLE 2. *Summary of Average Yields (1945–50) per 100 Plants in Trials of Potato Hybrids at Delhi, with Notes on Maturity and some Tuber Characters*

Hybrid or the local variety	*Hybrid No. 45*	*Hybrid No. 208*	*Hybrid No. 209*	*Hybrid No. 610*	*Phulwa*	*Gola*	*Darjeeling Red Round*
Yield in lb. of 100 plants	131·8	122·4	127·8	125·3*	118·2	91·6	115·9
Maturity	Medium	Medium	Medium	Medium	Very late	Early	Medium
Tuber-size	Large	Medium to large	Medium to large	Medium to large	Small	Medium to small	Medium to small
Tuber-shape	Round	Round to oval	Oval	Round	Round to oval-round, sometimes irregular	Round, sometimes irregular	Round, sometimes irregular

* Average for only 3 years (1947–50).

The hybrids as a group, besides being good yielders and medium in maturity, are moderately tolerant to the important virus diseases.

Hybrids Nos. 45 and 610 have poor keeping-quality under ordinary temperatures.

Reference may be made here to a difficulty encountered in the breeding-work. The semi-wild characteristics of the *desi* types were found to be dominant and thus narrowed down the scope of selection of desirable segregates. Moreover, incidence of virus diseases in the plains was found to be very high, and the most promising segregates selected during one year often faded away in the very next year. It became abundantly clear, as a result of the experience gained, that any large measure of success cannot be expected through the use of *desi* varieties and that it would now be necessary, (*a*) to use a much wider range of breeding material for study and selecting suitable parental types, and (*b*) to make provision for facilities to grow and maintain the hybrid progenies, raised from true seed, under conditions where the natural incidence of virus diseases is very low.

Long-term project: breeding for disease resistance.—A search for genes for resistance to specific diseases was specially made in the living collections available and the results of the breeding-work are briefly summarized below.

Work was concentrated chiefly upon the breeding of late-blight-resistant varieties. For this purpose the late-blight-resistant species *S. antipoviczii* and *S. demissum* were crossed with *S. tuberosum*, and several progenies raised. Certain undesirable wild characteristics of *S. antipoviczii* could not be eliminated completely even after a series of back-crossings with the *S. tuberosum* parent. *S. demissum* in this respect was found to be a more desirable parent than *S. antipoviczii*. A natural epidemic of late blight in 1936 made it possible to select out the following *demissum-tuberosum* hybrids, obtained through Russian sources, as suitable parents for breeding late-blight-resistant potatoes.

About 80 different crosses between the resistant *demissum* hybrids and important Indian and exotic commercial potatoes were studied. Among the parents used were the three most important Indian commercial potatoes, Phulwa, Darjeeling Red Round, Gola, and also Italian White Round, a variety imported from Italy under the name Riccio and once extensively grown in Bombay and its surrounding provinces. Among the foreign exotic types used as parents, mention may be made of Epicure, President, Katahdin, Ekishirazu, Imperia, and Seedling 41596. Besides these, some of the hybrids evolved at the Simla Potato Breeding Station were also used.

From a series of back-crosses a progeny of about 5,000 seedlings was raised from time to time, and, after elimination of undesirable types, 700 were chosen for a detailed study under field and laboratory conditions. Most of these hybrids were tested under controlled conditions by artificially creating epiphytotics (Plate 4, fig. 2; Plate 5, figs. 1, 2) of the late-blight fungus (*Phytophthora infestans*). About 40 of the hybrids have consistently shown a high degree of resistance both under field and laboratory conditions. The inoculum in all these tests was always secured from the natural infection in the field, and at this stage of the work there is no evidence to show the presence in India of physiologic forms in *P. infestans*.

Some among the above hybrids, which now constitute important breeding material for further work, have approached commercial standards in yield, tuber-size, &c., but certain wild characters like long stolons and fibrous root-system have still to be eliminated before they can be called truly commercial. Further work is in progress.[1]

Although differences in varietal resistance to *Alternaria solani* have been noticed, no variety possessing a sufficient degree of resistance for breeding-work has yet been discovered. The testing work in connexion with the late blight and early blight was done in collaboration with the Division of Mycology of the Indian Agricultural Research Institute.

Work on virus diseases has hitherto been directed towards developing tolerant varieties, and a certain measure of success has been achieved. It has, however, been realized that the permanent solution of the problem does not lie in the production of varieties possessing tolerance to important viruses. In the absence of authentic knowledge about the virus diseases important from the commercial point of view in this country, no special study could be made. The preliminary work had, however, indicated, as mentioned earlier, that the problem of virus diseases in India is essentially similar to that of the other potato-growing countries. Breeding-work has evidently to be directed towards developing varieties possessing field-immunity to virus X and virus A, resistance to leaf-roll, and tolerance to Y. Leaf-roll resistance has been found in Imperia, and recently in an Indian commercial variety, Sathoo. This is a late variety with light-red, deep-eyed, and humped tubers; its usefulness is therefore restricted to breeding-work.

For breeding types field-immune to virus X and virus A, the requisite breeding material has recently been secured from the U.K. through the kindness of Dr. Cockerham and Dr. Black of the Scottish Society for Research in Plant Breeding.

Genetical Studies

Reference has already been made to the wild and cultivated species of tuber-bearing Solanums. The utilization of the possibilities immanent in these is by no means an easy task; and the plant-breeder's ideal of breeding high-yielding potatoes resistant to disease and frost, rich in protein and vitamins, cannot be expected to be successfully achieved without proper understanding of the genetical basis of the characters involved. Transfer of the desired genes into our domestic potatoes is also governed by the essential condition that the species the breeder is dealing with can be crossed either directly or indirectly with his commercial varieties. The several potato species (of which about 50 are now available at the Simla Station) not only constitute a polyploid series: $2n = 24, 36, 48, 60$, and 72), but also belong to different genetic groups,

[1] Besides the above hybrids a number of late-blight-resistant hybrids were also secured from Dr. Black of the Scottish Society for Research in Plant Breeding and Genetics, Scotland, and also a number of *demissum-tuberosum* hybrids originally bred by Dr. R. N. Salaman and later worked up by Dr. Carson of the School of Agriculture, Cambridge. The Cambridge material was secured through the kindness of Prof. Sir F. L. Engledow of Cambridge University.

thus rendering it often difficult to effect crosses even between species with identical chromosome numbers. The study of crossability relationships and allied genetical problems was therefore undertaken. The results obtained are briefly referred to below.

1. *Crossability studies. Relationships between groups*

Crossing tests showed that it is relatively easy to cross between any two in the large diploid group of species belonging to the series Commersoniana which includes the following species: *S. chacoense*, *S. caldasii*, *S. garciae*, *S. schickii*, *S. subtilius*, *S. jujuyense*, and *S. gibberulosum*.

It has not been possible so far to cross the Commersoniana series of species with other diploids belonging to the series Cardiophylla (*S. cardiophyllum* and *S. lanciforme* represent this group in our collection) and Pinnatisecta (*S. jamesii*, representing this group). Similarly the diploid *S. polyadenium* (belonging to the series Polyadenia) could not be crossed with species belonging to the series Commersoniana, Pinnatisecta, and Cardiophylla. On the other hand, however, it has been found possible to effect crosses between some diploid species belonging to the series Tuberosa (*S. aracc-papa*, *S. simplicifolium*, *S. rybinii*, and *S. ascasabii*) with the diploids of the series Commersoniana.

The crossability relationships of species with higher chromosome numbers are still obscure. The ease with which successful hybrids can be obtained does not seem, in the potato, to depend entirely on chromosome numbers. As an example it may be stated that it is easier to cross the tetraploid *S. tuberosum* with *S. antipoviczii* ($2n = 48$) and *S. neoantipoviczii* ($2n = 48$), both belonging to the series Longipedicellata, but crosses with *S. acaule* (belonging to the series Acaulia, all members of which possess $2n = 48$ chromosome) can be obtained only with difficulty. It has not been possible at Simla to cross *S. tuberosum* with *S. acaule*, but the cross is reported to have been successful elsewhere.

S. tuberosum ($2n = 48$) can be crossed with the hexaploid *S. demissum* (belonging to the series Demissa) fairly easily; *S. demissum* when used as female gives a greater measure of success than when it is used as male parent.

From the above it would seem that the relationship of most of the species is still obscure, but on the basis of the crossability survey so far made it would appear that some of the species belonging to series Commersoniana, Longipedicellata, Tuberosa, and Demissa are closely related.

2. *Sterility studies*

(i) *Sterility due to non-flowering.*—In the plains of India where potatoes are grown under short winter days, few commercial varieties come to bloom and hardly any of about 20 species under observation flowered.

(ii) *Male sterility.*—The absence of pollen, or, when it is present, its poor quality, is the cause of the most important type of sterility in *S. andigenum* and *S. tuberosum*, and it occurs but very rarely in other South American species of potatoes. Out of 62 *S. andigenum* varieties studied, 23, i.e. about 37 per cent., were found to be completely sterile, but out

of 247 varieties of *S. tuberosum* examined, 144, i.e. over 70 per cent., lacked pollen [12]. This high pollen sterility in cultivated potatoes seriously limits the choice of breeding material.

The absence of pollen was found to behave as a dominant genetic character [3]. Study of some crosses at Simla between several *S. tuberosum* varieties gave results similar to those obtained by Salaman [13] and Salaman and Lesley [14], and could be explained on a simple monofactorial assumption. However, more complex ratios were also obtained that could not be explained in simple Mendelian terms.

(iii) *Sterility resulting from self- and cross-incompatibility.*—Our studies have shown that self- and cross-incompatibility is common in the diploid group of potatoes. The presence of self-incompatibility has been established in several species, including *S. caldasii*, *S. chacoense*, *S. subtilius*, *S. jujuyense*, *S. simplicifolium*, *S. saltense*, *S. jamesii*, *S. aracc-papa*, *S. rybinii*, *S. parodii*, *S. goniocalyx*, *S. calcense*, *S. garciae*, *S. lanciforme*, and *S. verrucosum*.

Not all the diploid potatoes have been found to be self-incompatible, and some varieties of *S. chacoense* [3, 15], for instance, are highly self-fertile, but *S. polyadenium*, *S. schickii*, and *S. gibberulosum* are completely self-fertile, and there is no evidence of self-incompatibility in them. Incompatibility has not so far been discovered in any other potato outside the diploid group.

It has been shown that 17 self-sterile varieties of *S. caldasii* could be grouped into 5 distinct intra-sterile but interfertile classes [15]. This established the presence of cross-incompatibility as a cause of sterility. Later work [12] showed that in the case of self-incompatible species, selfed seed can be obtained under certain specific conditions. Thus, when young buds (about 3–4 days before they are due to open) are fertilized with pollen taken from open flowers of the same plant, setting can be obtained.

Genetics of self- and cross-incompatibility.—Self- and cross-incompatibility in potatoes has been found to be genetic [6] and depends on factors that form a multiple allelomorphic series. The study of several crosses between self-incompatible potato varieties has shown that in their operation the sterility allelomorphs follow the oppositional factor hypothesis outlined by East and Mangelsdorf [16]. As a result of the study of progenies derived from 8 different crosses [15, 12], the presence of 11 sterility allelomorphs, S^1 to S^{11}, has been established. These factors in various permutations and combinations govern the behaviour of self- and cross-incompatibility relationships in several varieties belonging to the species *S. caldasii*, *S. chacoense*, *S. subtilius*, and *S. jujuyense*. There is evidence to show that the number of such allelomorphic factors is much larger than the number so far established; *S. aracc-papa* and *S. rybinii* have been shown to possess factors belonging to the same allelomorphic series, but their action is modified by the presence of additional modifying factors [12].

Sterility arising from other causes.—Stout and Clark [17] and later Clarke [18] have mentioned the case of a cross between two fertile species *S. fendleri* ($2n = 48$) and *S. chacoense* ($2n = 24$), where the F_1 hybrid

produced was completely self-sterile. Similar cases of sterility, arising from unbalanced chromosome numbers, were observed at Simla. Thus Clarke's cross [18] *S. fendleri* ($2n = 48$) × *S. chacoense* ($2n = 24$) and its reciprocal, *S. chacoense* ($2n = 24$) × *S. neoantipoviczii* ($2n = 48$) and its reciprocal, all gave fully flowering F_1 progenies that were completely pollen sterile.

Study of Floral Biology and Pollen Grains

Shape and size of pollen.—The fertile pollen grains are characterized by smooth, round, soft, or slightly granulated contents, whereas irregularly round, hyaline, and those devoid of contents indicate sterile pollens. The former when stained with haematoxylin solution are coloured deep blue, but the sterile pollen grains do not take any stain.

Size of pollen in cultivated potato and *S. andigenum* has been found to vary considerably. The range from 20·6 μ to 44·2 μ has been recorded in *S. tuberosum*. Seventeen other species of Solanum were examined and the size of their pollen grains studied. The variation in size ranged from 17·7 μ to 43·1 μ, the highest being in *S. leptostigma* and the lowest in *S. polyadenium*. The amount of pollen grains differs in different species and varieties. As has been pointed out by Whitehead *et al.* [19], this character could even be used for distinguishing some apparently similar varieties. For example, it has been stated that the variety British Queen, which may be sometimes confused with the variety Ballydoon, may be separated by the fact that the anthers of the former have practically no pollen grains, whilst those of the latter have a considerable amount of them.

Pollination.—This usually takes place in nature either by direct contact of the anthers with the stigmas (especially in those varieties where the stigma does not reach far beyond the anther cone), or through the agency of insects, mostly bumble bees (*Bombus haemaroidelis*), that are present at the time of flowering [3]. Wind or gravity has been found to be comparatively unimportant in the pollination of potato flowers [3].

The flowers of potato are borne in a cymose type of inflorescence and the length, colour, and pubescence of the peduncles and pedicels vary considerably in different species and varieties. The colour of the corolla varies from white, mauve, or yellow, and the shape of the corolla is usually rotate, stellate, or pentangular. Double corollas are sometimes recorded although we have not come across these ourselves. The stamens are usually arranged in a symmetrical column around the pistil. They may be pale yellow, yellow, or orange; a pale-yellow colour of the anthers is always associated with male sterility [3]. The filaments are usually white and are much smaller than the length of the anthers. The pistil is divided into three parts, the ovary, style, and stigma. The ovary is usually two-celled, and the style is erect and white. The lower third of the style has a number of minute hairs or papillae which can be observed through a hand-lens. The stigma is usually bilobed, but the lobation is not very distinct except in one or two varieties. Stigma characters were found useful in the classification of different species. The shape of the stigma, the degree of flattening, the presence or absence of a

medium notch, and also the size of the 'stigmatic triangle', have been found useful for this purpose. (As the stigma does not always fit like a cap on the style, a small triangular area is left along the lateral side of the stigma; this is called the 'stigmatic triangle'.) The sides and tips of petals contain epidermal hairs, which are regarded as important structures associated with the closing of the flower-buds [3].

Time of opening and closing of flowers.—These times vary with different species and varieties, but in general they are constant for each variety. Cloudy days and wet weather induce the closing of flowers, but a few varieties are not so sensitive to these conditions. Some species bloom only for a short period. For example, under Simla conditions *S. polyadenium* Greenm. remains open only for 5 or 6 hours in the morning. In other species, like *S. jamesii* Torr., flowers may remain open for about 11 hrs. a day [3].

Capacity for flowering.—Of the various species studied, it may be possible to group them as follows:

(*a*) Profuse flowering: *S. subtilius; S. caldasii; S. chacoense.*

(*b*) Moderate flowering: *S. demissum; S. polyadenium; S. rybinii; S. neoantipoviczii.*

(*c*) Poor flowering: *S. fendleri; S. andigenum.*

It was further observed that cool wet weather favours flower formation but dry weather suppresses it [3].

Crossing technique.—Under Simla conditions it has been found that large buds that are due to open next morning are most suitable for emasculation. This was usually done in the evening, as it was found that pollination was most effective after 36 hrs., i.e. on the morning of the day after. As the anthers are very small and the available pollen grains rather limited, the following convenient technique was devised [3]. As is well known, the anthers of potato normally open by an apical pore.

The anther is held between the thumb and the fore-finger with the tapering apex of the anther pointing upwards. The base of the anther is gently split by a pair of forceps, and by an upward movement of the forceps the pollen grains are collected near the connective. The smearing of the stigma with pollen grains is then achieved by bending the floral branch and bringing the stigma in contact with pollen grains on the connective.

Other Studies

Dormancy.—As potatoes harvested in the hills are dormant, they cannot be used as seed-stocks in the plains; hence the problem of dormancy assumed special significance. Experiments carried out by the authors [21] at Pusa (Bihar) showed that the most successful treatment to break the dormancy was to peel the tubers (leaving eyes intact) and to store them in moist sawdust for about a week. Experiments made with ethylene chlorhydrin gave varying responses. In general, whole tubers subjected to ethylene chlorhydrin vapour for about 24 hrs. gave good response, and this treatment, unlike the peeling method, which has a

limited commercial application for obvious reasons, holds out better promise from the commercial point of view.

Studies on propagation with potato 'tops' and sprouts.—Various methods which would reduce the seed-rate per acre became of interest during the Second World War; experiments on this line were conducted also both at Delhi and Simla. The results of these experiments have been published and are summarized below.

Potato 'tops' and eyes. From experiments conducted at Delhi with potato 'tops' and peelings of two varieties Phulwa and Gola, it was found [21] that 'tops', i.e. seed-pieces taken from the rose-end of the tuber, did not give very satisfactory yields:

Variety	*Kind of seed*	*Yields per 100 plants (lb.)*
Phulwa	Top tubers	33·4
	Half-tubers	45·2
	Whole tubers	51·5
Gola	'Tops'	10·4
	Half-tubers	27·8
	Whole tubers	27·7

It is, however, possible to compensate for the decrease in yield by adopting a closer spacing than is usual, and by adequate manuring.

Sprouts. Work carried out at Simla has established the possibility of utilizing potato sprouts for rapidly multiplying stocks for trials [19, 23, 24]; also, as it is possible to exercise selection and to eliminate those sprouts that are apparently unhealthy, this method helps in maintaining disease-free material.

This 'sproutling method' of potato-growing consists in raising the crop from detached sprouts, about 1 to 2 in. long. These sprouts are closely planted in a rich soil and in about a month's time they develop a crown of leaves besides the roots, which develop even earlier, and at this stage can be transplanted in the field. Experiments conducted at Simla for a few seasons with several varieties have shown that under suitable conditions the yield or size of tuber of the 'sproutlings' is in no way inferior to that secured from whole tubers.

Each potato tuber, when kept under suitable conditions of light and temperature, is capable of giving 3 (sometimes 4–5) successive crops (at intervals of 15–20 days each) of sprouts 1–2 in. long. Preliminary experiments carried out with 3 varieties of potato showed that on an average 18–28 sprouts can be secured from each tuber (see table opposite).

Sprouting capacity has been found to vary with different varieties, and some are capable of producing a much larger number of sprouts than others. Long sprouts if cut into pieces can also be utilized for raising 'sproutlings', and these give as good yields as the entire sprouts.

Preliminary experiments have shown that it is possible to transport potato sprouts in postal packets or railway parcels over fairly long distances. No appreciable loss in rooting-capacity has been observed if sprouts, packed properly, are so transported and utilized for planting

within about a week's time from the day they are detached from the tubers.

Variety	*Crop of sprouts*	*Average no. of sprouts per tuber*	*Total no. of sprouts per tuber*
Hybrid 2	1st	10·76	
	2nd	10·79	
	3rd	7·08	28·63
Hybrid 12	1st	5·75	
	2nd	5·68	
	3rd	7·08	18·51
Up-to-date	1st	7·82	
	2nd	8·62	
	3rd	7·88	24·32

The above results with sprouts refer to the Simla Substation; at Delhi, in the plains, the results have not been so satisfactory, possibly owing to the weather at the time when potatoes are normally planted. The question whether sprouts can be used for potato propagation in the plains therefore requires further experimentation.

Transfer of Potato Work to New Central Institute

After the first few years of work it became evident that with the increase in the size of the collections and the natural increase in the material resulting from breeding-work, additional staff and augmented laboratory and glass-house facilities would be required to carry the work in progress to its logical conclusion and to deal with other problems of potato improvement. The need of an additional station at a higher altitude where natural incidence of virus diseases is low, for growing, maintaining, and studying hybrid progenies raised from true seeds, has already been mentioned earlier in this article.

Proposals were therefore advanced for expanding the research work on potato-breeding and allied aspects. Since the Indian Council of Agricultural Research was unable to finance such a big long-term project the question of setting up a Central Potato Research Institute was taken up by the Government of India. Eventually such an Institute was established at Patna in 1949 under the directorship of Dr. S. Ramanujam. The stations at Simla and Bhowali (and also that at Kufri for Potato-Seed Certification) were transferred to the new Institute along with the full potato collections, and the large series of hybrids evolved during the investigations described in this paper. These form a basis for the new Institute to build upon.

Summary

The problems of potato improvement with special reference to potato-breeding are discussed. The work carried out mainly at the Simla branch of the Indian Agricultural Research Institute during the past 14 years is summarized.

The importance of study of large and varied collections with a view to discovering suitable parental material for breeding high-yielding and disease-resistant types of potatoes is stressed, and the various collections studied in this connexion are mentioned. In the earlier stages, work was concentrated on the breeding of varieties suited particularly for Indian conditions, by crossing the *desi* varieties with improved European and American varieties. As a result of this work a number of hybrids suited for long-day and short-day requirements for the hills and plains respectively have been evolved. Preliminary work connected with breeding of disease-resistant potatoes has been completed and satisfactory progress made in breeding late-blight-resistant varieties mainly through the use of the wild species *S. demissum*. Ancillary studies carried out on the genetics, crossability, sterility, pollen, floral biology, dormancy, &c., are referred to. Experiments on the possibility of commercial utilization of potato 'tops', eyes, and sprouts for propagative purposes have been made and the results obtained briefly narrated.

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FIG. 1. The Simla potato-breeding station. Terraced experimental plots

FIG. 2. Mat hut for testing late-blight resistance. Note the haulms suspended above the potted plants to be tested

FIG. 1. Late-blight-susceptible types, about ten days after infection

FIG. 2. Late-blight-resistant types, about ten days after infection

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FIELD EXPERIMENTS IN SELECTIVE WEED CONTROL BY PLANT-GROWTH REGULATORS

IV. THE EFFECT OF PLANT-GROWTH REGULATORS UPON THE PRODUCTIVITY OF GRASSLAND

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Introduction.—It is a basic principle of grassland management that if useful grasses and legumes are encouraged, the weed flora is automatically reduced. Conversely, if weeds are suppressed, the growth of useful plants is encouraged. In his discussion of pasture weeds and their ecological relationship to the pasture sward, Bruce Levy [1] stresses the importance of light as the chief factor controlling competition. Once a plant is shaded by a more vigorous rival it loses dominance and may ultimately be eliminated from the community. Seed germination is also governed by light stimuli, many species being highly sensitive to the different degrees of light and shade.

Nearly 20 years have elapsed since Martin Jones [2] first demonstrated at Jealott's Hill the influence of cutting and grazing management on the composition of pasture swards. In one classic experiment a field sown with a simple mixture of perennial rye-grass, cocksfoot, and wild white clover was divided into four parts and, after 3 or 4 years, merely as a result of varying the time and intensity of grazing, one area had become predominantly rye-grass, another cocksfoot, a third wild white clover, and the fourth a wilderness of thistles, bent, and Yorkshire fog.

Generally speaking, coarse and tall-growing weeds can be discouraged by hard grazing and cutting, and creeping and low-growing weeds by encouraging the taller and better grasses to develop. Good drainage, liming, and fertilizer application all help. Although the discovery of the selective herbicidal properties of plant-growth regulators has added a new weapon to the husbandman's armoury, these fundamental principles should not be ignored.

In an earlier paper [3] the present authors discussed the effectiveness of plant-growth regulators, especially the sodium salt of 4-chloro-2-methyl-phenoxyacetic acid (MCPA), for weed control in grassland and showed that it was possible, by the use of these compounds, to check infestations of thistles, buttercups, ragwort, and other common weeds and to reduce them to a negligible proportion of the herbage. In considering from a practical point of view the implications of such treatment it is necessary to make a clear distinction between (i) newly sown leys, which may be expected to be rather more easily damaged by plant-growth regulators than at a later stage of growth, and which are likely to be infested with both annual and perennial weeds, (ii) well-established leys and permanent pastures, infested only with perennial weeds, and (iii) grasses grown for seed.

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Experimental Results

Newly sown leys.—Grass and clover leys are commonly established by undersowing with a cereal nurse-crop in spring. If plant-growth regulators are to be used to eradicate weeds in undersown cereals, it is necessary to take into account their effect on the young ley. Field trials in 1944 showed that MCPA applied a few days after seed sowing seriously damaged clovers and, to a less extent, grasses. Trefoil, in particular, was very sensitive. These results were confirmed in 1945, when it was observed that later applications some two months after sowing did much less harm. A further series of trials, designed to study the effect of MCPA on the clover-content of young leys, was undertaken in 1946. Seven of the trials were on undersown leys and the remaining three were without a nurse-crop (Table 1). MCPA was applied at two

TABLE 1. *Weed-killing Trials on newly sown Leys, 1946. Location of Centres*

Centre no.	*Location*	*Nurse-crop clean (c) or weedy (w)*	*Seeds-mixture*	*Date of sowing*	*Dates of MCPA application*
3 d	Easthampstead, Berks.	Barley (c)	?	?	Apr. 17 May 21
22	Fonthill Bishop, Wilts.	Barley (c)	Cocksfoot/white clover	Apr. 30	May 2 May 25
23	Nr. Selby, Yorks.	Oats (c)	Rye-grass/trefoil/red clover	Mar. 15	May 1
24	Wimborne, Dorset	Barley (c)	Cocksfoot/white clover	Late Mar.	Apr. 26 May 16
25	Penshurst, Kent	Wheat (w)	Rye-grass/timothy/trefoil/red clover	Mar.	June 7 June 23
26	Nr. Tunbridge Wells, Kent	Barley (w)	Rye-grass/red clover	Early Apr.	May 11 June 7
27	Snaith, Yorks.	Barley (w)	Rye-grass/alsike/white and red clover	?	May 16 June 12
28	Mayfield, Sussex	.. (c)	?	May 9	June 7 June 24
29	East Clandon, Surrey	.. (w)	Cocksfoot/white clover	Apr. 5	June 21
30	Staindrop, Co. Durham	.. (w)	?	Late Apr.	May 29 July 1

stages of growth at 1 and 2 lb./acre as a spray and at 2 and 4 lb./acre as a dust, the first application being made before or soon after emergence, and the second application when the clovers were past the seedling stage and had at least four true leaves. The results indicated that clovers were more seriously damaged if treated with MCPA before emergence or as young seedlings than if treated later, and that leys suffered more without a nurse-crop than when undersown. Taking the results as a whole, the clovers were badly suppressed on just over half the treated plots. Considering only the late applications to undersown weedy crops,

admittedly in a wet year which favoured the development of young leys, the clovers were seriously affected in only two cases out of twelve and at one centre were decidedly increased (Table 2). In the following year at Jealott's Hill late application of 2 lb. MCPA per acre to clean crops of spring oats and barley in a period of prolonged dry weather killed 60 per cent. of the undersown clover. Where 8 lb. MCPA per acre was applied, the clover was almost entirely eliminated. Recent American experience [4] indicates that DCPA may be more damaging to red clover, alsike, and sweet clover than MCPA.

TABLE 2. *Weed-killing Trials on newly sown Leys, 1946. Effect of MCPA on Clovers*

	Effect of MCPA treatment on clovers { − seriously depressed; o not appreciably affected; + substantially increased							
	Early application				*Late application*			
	Spray		*Dust*		*Spray*		*Dust*	
Centre no.	*1 lb./ acre*	*2 lb./ acre*	*2 lb./ acre*	*4 lb./ acre*	*1 lb./ acre*	*2 lb./ acre*	*2 lb./ acre*	*4 lb./ acre*
3 d	o	o	o	—	—	—	—	—
22	o	—	—	—	o	o	o	o
23	o	o	o	o	..	..	..	..
24	—	—	—	—	—	—	—	—
25	o	o	o	—	+	+	—	—
26	o	o	—	—	o	o	o	o
27	o	—	—	—	o	o	o	o
28	—	—	—	—	—	—	—	—
29	—	—	—	—	..	..	..	..
30	o	o	o	o	—	—	—	—

Pre-sowing application of MCPA.—When it was known that MCPA applied soon after sowing might impair the quality of undersown swards by reducing their clover-content, experiments were begun in the greenhouse to study the persistence and effect of MCPA applied to the soil before the seeds were sown. In two experiments conducted in 1945, one in the spring and one in the late summer, grass and clover species were sown in soil to which MCPA had been applied at rates equivalent to 1–8 lb./acre 2, 4, 8, or, in certain instances, up to 19 weeks previously. Of the species tested Italian rye-grass was the least sensitive, followed by perennial rye-grass. Next in susceptibility came cocksfoot, timothy, late-flowering red clover and wild white clover, and finally broad red clover and S100 white clover. Under the conditions of the experiments the minimum safe period between MCPA application and seed-sowing, without affecting germination or subsequent yield, was 8 weeks for Italian rye-grass, 8–10 weeks for perennial rye-grass, and not less than 10–13 weeks for the remaining species, assuming a rate of application of 2 lb./acre. Italian rye-grass was unaffected by 1 lb. MCPA per acre applied only 4 weeks before sowing. Mitchell and Marth [5], working with *Poa pratensis*, *Agrostis alba*, and *Festuca rubra*, found that seeds

sown 5 weeks after the soil had been sprayed with DCPA acid at ¾–3 lb./acre germinated and developed quite normally. In the dry early summer of 1946 Escritt [6] observed that the germination of rye-grass, fescue, and bent was severely affected by MCPA at 2–6 lb./acre applied to the soil less than 10 weeks before sowing, but that DCPA treated plots were unaffected. When the experiment was repeated under wetter conditions in the autumn, however, the inhibiting effect of MCPA was much less marked and lasted no more than 5 weeks. In greenhouse experiments DCPA at 2 lb./acre had an inhibiting effect which lasted for 2–3 weeks.

Permanent pastures and well-established leys.—In view of the adverse effect on newly sown clovers, it seems that the best use of plant-growth regulators as grassland weed-killers can be made on permanent pastures and well-established leys. A preliminary indication of the type of result which might be expected was obtained in 1946 when sample hay-cuts were taken from one of the buttercup trials described in the previous paper [3] (Centre No. 5 b). On June 25, 6½ weeks after treatment with MCPA spray or dust at 2½, 5, or 10 lb./acre, the total cut from the treated plots contained 2·1 tons of useful grasses and legumes and 1·9 t. of weeds and weed grasses per acre, whereas that from the untreated plots contained only 1·9 t. of useful herbage but 4·9 t. of weeds. It is clear from these figures, which relate to the fresh weight of green herbage immediately after cutting, that in the short time that had elapsed since treatment the grasses had not yet sufficient opportunity to benefit fully from the very appreciable reduction in competition with weeds. In other trials conducted in the same year the removal of weed infestation by MCPA-treatment produced a striking increase in the efficiency with which the treated plots were grazed. Marth and Mitchell [7] in America found that DCPA applied to a regularly mown sward infested with narrow-leaved plantain (*Plantago lanceolata*) caused an initial check to the grasses, but that later growth was much more rapid as a result of reduced weed competition. In some instances up to 80 per cent. more grass was present on the treated plots than on the untreated. In another instance, although the total herbage was reduced by one-tenth, the quantity of grass it contained was greater by 40 per cent.

The nine buttercup trials conducted during the 1946–7 season, also described in the previous paper [3], were all harvested at the hay-stage and the yields of useful herbage (i.e. grasses and clovers) and weeds recorded separately. At the majority of centres the autumn application of 2 or 4 lb. MCPA per acre significantly increased the yield of useful herbage, the average increase from the 2 lb. rate being equivalent to 5·2 cwt. dry matter per acre. The spring treatments, though providing effective weed control, failed to improve herbage yields, probably because insufficient time had elapsed for any beneficial effect to be felt (Table 3). Fertilizers, on the other hand, gave better results in spring than in autumn. The yield of clover, which was recorded at four of the nine centres, was significantly reduced by MCPA-treatment in nearly every case, although the 2 lb./acre rate on the whole caused less damage than the 4 lb./acre rate (Table 4). It is, however, important to realize that the average results summarized in Table 4 give only a partial and

TABLE 3. *Herbage Yields from 1946–7 Buttercup Trials when cut for Hay in 1947*

Centre no.	*Type of grassland*	*Time of treatment*	*Yield of useful herbage (cwt. D.M./acre) MCPA applied (lb./acre)*		
			0	*2*	*4*
13	Ley	Autumn	15·4	26·8*	29·8*
		Spring	16·4	13·6	12·0
14	P. grass	Autumn	11·0	20·6*	18·0*
		Spring	12·8	22·2*	20·6*
15	P. grass	Autumn	7·8	8·2	8·6
		Spring	8·4	7·2	7·4
16	Ley	Autumn	23·2	34·8*	36·4*
		Spring	24·8	28·6	29·0
17	P. grass	Autumn	32·6	36·6*	33·4
		Spring	35·8	33·2	34·8
18	Ley	Autumn	7·6	9·4*	9·6*
		Spring	7·0	3·6†	5·6†
19	P. grass	Autumn	13·2	15·4*	13·2
		Spring	14·8	13·6	14·4
20	P. grass	Spring	31·6	27·8†	26·6†
21	Ley	Autumn	29·6	30·8	30·6
		Spring	19·8	19·2	23·4

* Significantly greater than without MCPA-treatment.
† Significantly less without MCPA-treatment.

indirect estimate of the value of MCPA for weed control. The trials were perforce carried out under hay conditions, so that from a short-term viewpoint MCPA-treatment merely resulted in a lower total yield of hay, but buttercups are less objectionable in hay than in pastures which are grazed or cut for artificial drying and, indeed, are less unpalatable than thistles or ragwort. From a general point of view, therefore, the effect of MCPA on the total yield of useful herbage is the most significant factor.

TABLE 4. *1946–7 Buttercup Trials: Summary of Results*

	Average yields (cwt. D.M./acre)					
	MCPA application (lb./acre)					
	Autumn			*Spring*		
	0	*2*	*4*	*0*	*2*	*4*
Total useful herbage .	17·6	22·8	22·4	19·0	18·8	19·4
Buttercups* . .	8·3	2·3	1·7	7·0	1·9	2·0
Clover* . . .	2·4	1·8	0·5	2·8	0·6	0·3

* Average of centres where yields were recorded.

Influence on botanical composition.—Although well-established clovers are often seriously depressed by MCPA and DCPA, groundsmen and others who regard wild white clover as a weed have found it hard to eradicate. Escritt [6], for example, states that repeated applications of plant-growth regulators are usually needed for satisfactory control and cites a case where single dressings of 1–2 lb./acre DCPA diethylamine salt resulted apparently in stimulation. The same happened in the first control experiment on thistles at Jealott's Hill in 1945 where clover was more vigorous on plots dusted with 5 lb. MCPA per acre than on untreated plots, although 20 lb./acre caused a severe setback. Since the clovers can be nursed back into full production by suitable management, so long as they are not completely eliminated, any loss in productivity is only temporary and more than compensated by the removal of weeds. A fair degree of injury can therefore be tolerated.

A notable feature of the Jealott's Hill thistle experiment was the increased productivity of bent that accompanied the removal of weeds. According to Albrecht [8] some Agrostis strains are readily injured by DCPA sprays, but the degree of resistance varies from one strain to another. Marth, Toole, and Toole [9] found that timothy, though temporarily yellowed, was less susceptible to DCPA than bent. Rye-grass, fescue, and meadow grass were much more resistant and remained dark green even when growth was slightly arrested.

Grasses grown for seed.—In an early experiment at Jealott's Hill [10] timothy grown for seed and treated when 6–14 in. high was unaffected by dressings of 4 lb. MCPA per acre. The Swedish workers Åberg, Hagsand, and Väärtnöu [11, 12] also found that timothy could be safely sprayed with 2 lb. MCPA. per acre without affecting the quality of the seed. In an experiment at Brunna near Uppsala in 1947 the yield of timothy seed was increased by approximately 30 per cent. through weed control by MCPA, whilst the thousand-grain weight and percentage germination were unaffected. Although germination of smooth-stalked meadow grass suffered considerably, the quality of red and meadow fescue seed was only slightly impaired. Clover, which occurred as a weed on the grass-seed plots, was moderately well controlled. Gelin [13] successfully used 1–2 lb. MCPA per acre for weed control in red and meadow fescue without affecting yield or quality of seed. At Jealott's Hill, cocksfoot treated when 1–1½ in. high was reduced in growth even by 1 lb. MCPA per acre, and Klingman [14] in America observed that this grass derived less benefit from the reduction in weed competition after DCPA-treatment than other less dominant species such as Russian wild rye-grass, crested wheat-grass, and buffalo grass.

Discussion

Palatability and toxicity of treated herbage.—Reference has already been made to the eagerness with which MCPA-treated plots were sometimes grazed in comparison with others that had not been so treated. Some authors have suggested that this phenomenon may not be due entirely to the elimination of undesirable and unpalatable weeds. Some, indeed,

consider that the lush growth and general improvement in palatability immediately following treatment with plant-growth regulators may induce grazing animals to feed on poisonous plants which they would otherwise avoid [15]. At present there is little scientific evidence to prove or disprove this hypothesis. It is generally recommended meanwhile that grazing animals should be kept out of sprayed areas containing poisonous plants until the observable effects of the treatment on the poisonous species are complete.

There is no indication that the plant-growth regulators themselves do any harm in the proportions commonly employed for weed control. The odour is not objectionable to stock, nor is palatability reduced by spraying. The 50 per cent. lethal dose for mice, when injected subcutaneously or intravenously, was found by Bucher [16] to be 280 mg. DCPA per kilogram of body-weight; and that for chicks, when administered orally in aqueous solution, was found by Bjorn and Northen [17] to lie between 380 and 765 mg./kg. Mitchell and Marth [18] fed 200 mg. DCPA daily to small experimental mammals with no apparent ill effects. The tolerated doses of DCPA administered orally to mice, rats, rabbits, and guinea-pigs were found by Hill and Carlisle [19] to be 125, 166, 200, and 333 mg./kg. respectively. The largest dose tolerated by monkeys without serious after-effects was 214 mg./kg. Assuming an application of 4 lb. DCPA or MCPA per acre to young grass yielding 10 cwt. dry matter per acre, the maximum daily quantity a cow grazing this herbage could possibly ingest would be about 50 gm., or 90 mg./kg. of body-weight. In practice only a fraction of this amount would be taken. In an experiment by W. S. Ferguson at Jealott's Hill in 1945 the health of two cows receiving MCPA daily for 16 days in their afternoon feed was unaffected, neither was their milk tainted. The amount of MCPA fed was progressively increased during the experiment from 0·9 gm. to 18 gm. per cow per day together with a certain quantity of impurities. It is unlikely that this figure would be exceeded under normal grazing management, as even a slight shower is sufficient to wash much of the active principle into the soil. In the same year Mitchell, Hodgeson, and Gaetjens [20] examined sheep and cows grazing pasture sprayed with 215 gallons/acre of a mixture containing 0·15 per cent. DCPA acid and 1·5 per cent. 'Carbowax 1500' polyethylene glycol and could find no ill effects. Neither was there any indication of cumulative toxicity as no pathological symptoms attributable to DCPA could be found in a cow which had received 5·5 gm. DCPA daily for 106 days, nor was DCPA detected in the milk, although at the end of this period some 8 p.p.m. were present in the blood-serum. Grigsby and Farwell [21] recently described the results of an experiment at the Michigan State College Agricultural Experiment Station in which various types of livestock, including dairy and beef cattle, sheep, and pigs, were enclosed in 3-acre paddocks each divided into two halves, the one being sprayed with DCPA sodium or alkanolamine salt at 4 lb. acid equivalent per acre at the beginning of the experiment and the other six days later. No preference was exhibited for sprayed or unsprayed areas, nor were any appreciable changes in weight of any of the animals recorded during the subsequent fortnight. Milk

production was maintained or increased, though there was some evidence of taint, possibly due to external contamination.

Practical applications.—Reviewing progress already made towards more efficient grassland utilization in the United Kingdom, Sir William Gavin [22] mentions the use of better varieties and strains of seeds and special-purpose seeds—mixtures to provide more continuous grazing throughout the summer, 'staggering' of young leys by sowing with and without nurse-crops, better control of grazing, more harrowing and topping, and application of nitrogenous fertilizers to give early and late bites, more grass for drying and silage-making, and earlier and better-quality hay. The latest developments include: close folding or strictly rationed grazing with electric fencing; production of more herbage by heavy rates of fertilizer application, particularly with nitrogen; increased production from permanent grass by the same intensive treatment as is given to leys; and increasing skill in conservation, particularly in mechanizing the process of ensilage. The possibility of using plant-growth regulators for selective weed control in grassland marks a further advance, offering a quick alternative to repeated topping or the more drastic treatment of ploughing and reseeding. The partial suppression of clover, which may be a serious disadvantage in young leys, is of less consequence on older grass and it is on the latter that the use of plant-growth regulators would be mostly recommended.

There still remains the problem of resistant weeds, chief among them being bracken. Other weeds of a more shrubby nature, such as hawthorn and brambles, show signs of being controlled by another plant-growth regulator, 2, 4, 5-trichlorophenoxyacetic acid, popularly known as TCPA or 2, 4, 5-T. Others that are relatively resistant to the sodium salts of MCPA and DCPA may be more amenable to treatment with the esters and amine salts of these two compounds. Provided then that the present limitations of the method are clearly understood and that the observed increases in useful herbage, as determined from hay-cuts, are reflected in the live-weight gains and milk yields of grazing stock, the use of plant-growth regulators for selective weed control can play a major part in raising the productivity of second-rate pastures. This in itself may help to solve the problem of bracken control for, as Bruce Levy says in his original context [1] 'The more cattle hill-country can carry in virtue of a good grass-cover the easier is the control effected, and the more cattle that must be withdrawn from the hills due to the lack of supporting feed the more rapid is the deterioration and spread of bracken fern.'

Summary

Experiments are described in which the total yield of useful grasses and legumes from permanent grass and established leys was significantly increased by MCPA treatment as a result of reduced weed competition. MCPA was also successfully used for weed control in timothy grown for seed. Clovers in newly sown leys were badly damaged by weed-control treatment with MCPA sodium salt at 2–4 lb./acre, although less harm was caused when the ley was protected by a nurse-crop and application

was delayed until the clovers were past the seedling stage. Pre-sowing application of MCPA to the soil adversely affected germination of grasses and clovers for at least 2–3 months, Italian rye-grass being the least sensitive and broad red and S100 clover the most sensitive of the species tested. Established clovers in older leys and permanent pastures were sometimes partly suppressed by MCPA treatment but recovered after suitable management. The toxicity of DCPA and MCPA is such that, at the rates commonly employed for weed control, neither of these substances is likely under normal management to affect the health or taint the milk of grazing animals.

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THE GENETIC HISTORY AND BREED-STRUCTURE OF BRITISH FRIESIAN CATTLE

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THE cattle of the western coastal regions of Germany and Holland have frequently been imported into this country in the past. In fact, Dutch cattle imported into the Holderness region of Yorkshire are said to have played a considerable part in the development there of the Shorthorn breed. In the second half of the nineteenth century, many black-and-white cattle were introduced from Holland, mainly into East Anglia. Although indiscriminate importation was forbidden by the Act of 1894, the type stayed in existence and in 1909 a group of breeders formed the British Friesian Herd-book. For the first two years entry was purely by inspection, and in this period about 1,100 bulls and 7,000 cows were registered. The breed increased in size steadily to about 25,000 milking cows in the 1920's and then numbers remained fairly constant until the middle thirties; there has been considerable expansion since then, and now it numbers about 80,000 milking cows. Since 1909 there have been several organized introductions of new blood: in 1914 and 1936 from Holland, in 1922 from South Africa, and in 1946 from Canada. All the earlier importations have had considerable influence on the present state of the breed. In 1921 a grading-up system was started with four stages. In the first grade, A, a cow can be entered by inspection and her offspring by a pedigree bull entered in grade B. After four such top-crosses the female offspring can be entered in the herd-book as a full-pedigree cow. Although entries in the A register were numerous in the first years, they declined considerably after the agricultural slump in the early twenties and numbers remained small until the expansion started around 1935. Up to the present the effect of the scheme has been slight.

To the geneticist, therefore, the breed has many interesting features. In this work we are concerned with the general structure of the breed and the breeding policies followed as they are revealed by the analysis of the effects of the various importations, of the importance of individual animals and herds, and of the grading-up system.

Material and methods used.—In the general analysis of the breed in different periods, it was decided to confine the work to the pedigrees of registered females. The number of bulls registered is always much less than that of females—in general less than one-third—and the selection of bull calves for registration is a potential source of bias. There is reason to believe that almost all of the heifers that live are registered. The parents of registered heifers may therefore be taken as representative of the breeding stock in use at that time. The analysis was done for 5 periods at 7-year intervals from 1917 to 1945, that being the most recent herd-book available when this section of the work was done. In

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each period, 80 registered female calves were taken at random from the full herd-book and their pedigrees analysed.

To do such work by the construction of the complete pedigrees going back 6 or 7 generations and involving perhaps 200 animals would be much too laborious. For this reason we used a modification of the sampling technique originally used by McPhee and Wright [1], and usually referred to as 'Wright's short method'. This is a very valuable method for the estimation of average values of inbreeding and relationship over the breed as a whole. In its original form, two lines of the pedigree were drawn back, one from the sire's side and one from the dam's. The choice of whether in any particular case to draw the line through male or female is determined by either tossing a coin or consulting a table of random numbers. If the same ancestor appears in the lines on both the sire's and dam's side, then the animal is obviously inbred. This is usually known as a 'tie'. Wright showed that the average degree of inbreeding in the population is equal to half the proportion of animals showing such a tie. Similarly, the direct relationship of an animal to the breed (i.e. the relationship through progeny only) is equal to the proportion of lines tracing through that animal.

In McPhee and Wright's analysis of the Shorthorn breed they found that the degree of inbreeding was high, about 25 per cent., so that there was a tie in one-half of the pairs of lines drawn. In the Friesian breed, however, the inbreeding is fairly low, not more than 2 per cent., so that one would not expect more than one tie in 25 animals. As the accuracy of the estimate depends on the total number of ties observed, it is obvious that any method of increasing the possible number of ties with the same amount of labour is advantageous. This can be done by drawing out more than 2 lines for each animal. Suppose we draw out the pedigree completely to the 8 great-grandparents and draw a line at random from each of them. We have then $4 \times 4 = 16$ possible inbreeding ties (the same ancestor on both sire and dam's side) so that there are 2 possible ties per line drawn compared with half a tie per line in the 2-line method. This was the technique that was used. The average inbreeding is then one-half the actual ties divided by the possible ties. However, it was found that the small proportion of very close matings (as, for instance, a half-sib mating giving 4 ties) contributed greatly to the standard error of the final estimate. However, the layout of the herd-books is such that the extent of close inbreeding could rapidly be estimated from a very large number of matings. To this was added the estimate of the remainder of the inbreeding obtained from the earlier method. The standard error of the resultant estimate was less than one-half that to be expected from the usual 2-line method. In this method the direct relationship of an animal to the breed is obtained as before.

The influence of the 1936 importation was also studied in more detail and at closer intervals by drawing out completely the pedigrees to include ancestors born before 1936. This allowed a more complete analysis of the way in which the influence of the importation spread throughout the breed.

Influence of the importations.—The proportion of lines tracing back

to the different importations and therefore the proportion of genes derived from them is shown in Table 1 and Fig. 1. The column 'grading-up' refers to genes introduced through the grading-up scheme and this

TABLE 1. *Percentage Contributions of the Foundation Stock and Importations to the Breed*

Year	*Foundation stock*	*1914*	*1922*	*1936*	*Grading-up*
1917	83·0	17·0	..	..	..
1924	56·1	39·9	4·0	..	..
1931	31·6	56·2	12·2	..	Negligible
1938	26·4	48·9	18·6	6·2	0·2
1945	17·2	40·6	17·9	24·3	0·4
Size of importation	..	39 bulls 20 cows	40 bulls 62 cows	47 bulls 48 cows	..

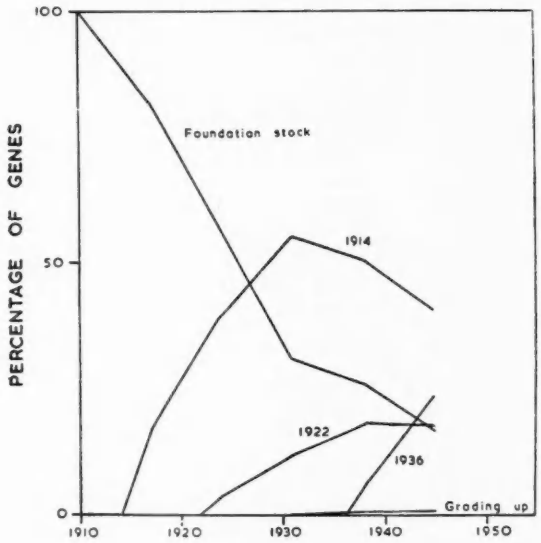


FIG. 1

will be discussed in more detail later. As would be expected, the contribution of the foundation stock has been declining continually in the face of the several importations. Now only about one-sixth of the genes in the breed are derived from it. The 1914 importation rose rapidly in importance to contribute 56 per cent. of the genes in 1931, but since then its influence has declined slightly. The 1922 importation never had an equal effect and is now declining after reaching a peak, when it con-

tributed 18 per cent. of the genes. The effect of the 1936 importation is still increasing, although the indications are that it will level off at about the 35 per cent. level or slightly below it. Examination of the rate of increase in importance would suggest that in 15 years the spread in influence of an importation over the whole breed is almost complete. In the period from 10 to 15 years after an importation it is therefore possible to give a reasonable estimate of its over-all effect.

The different importations varied somewhat in number and it seemed of interest to get some estimate of the average influence of the individual animals in the different groups. The obvious measure at any time would be the average number of genes in the breed derived from each gene in the imported animals. This is, however, complicated by the expansion of the breed. It is necessary, therefore, to consider the average effect of the individual animals in an importation against the background of the breed as it was when they were used in it—say, 2 years after the importation. This will give us a measure of the effect of the importation relative to the size of the breed. We may calculate a rough 'maximum reproductive factor' by multiplying the observed maximum percentage in Table 1 by the size of the breed 2 years after the importation and dividing by the total number of animals in the importation. By this means the relative effects of imported bulls and cows can also be estimated (Table 2).

TABLE 2. *The Maximum Reproductive Factor for the Importations*

Importation	*Bulls*	*Cows*
1914	47	40
1922	42	14
1936	70	20

The figures for the 1936 importation will probably increase slightly, as its effect has not yet reached its peak. The relative influence of the sexes can be seen in the table. In the first importation, the cows had almost as much effect individually as the bulls. For the last 2 importations, the cows have less influence: on the average about a third as much as the bulls.

The spread of the influence of the 1936 importation was then examined in more detail, and for this purpose random samples of 200 females and 100 males were taken from the herd-book in each of the years chosen. Table 3 shows the percentage of genes derived from the importation in animals registered in the different years. The figures for males and females have standard errors of about 1·4 and 2·0 per cent. respectively. The selection for registration of male calves with a high proportion of imported blood is clearly shown in the earlier years.

Turning to the females, as derived from a more representative sample of the parents used at the time, the proportion of animals containing any imported blood is given in Table 4.

In 1938 the contribution is almost completely from the daughters of imported sires. As the genes spread into a higher proportion of animals

TABLE 3. *Percentage of Genes in Registered Animals derived from the 1936 Importation*

Year	*Males*	*Females*
1938	15·4	6·2
1940	20·6	12·6
1943	24·1	20·4[1]
1945	26·0	24·1
1947	28·7	28·2

TABLE 4. *Percentage of Females carrying any Imported Blood*

Year	*Females carrying any imported blood*	*Proportion of imported blood in such animals*
1938	14·0	44·0
1940	42·0	30·0
1943	67·0	30·0
1945	87·0	28·0
1947	89·0	32·0

the imported blood in such animals declines. The deliberate decision of some breeders of bulls not to use imported bulls until their progeny tests were available probably accounts for the persistence of 11 per cent. of females with no imported blood in 1947 as compared with 13 per cent. in 1945. The spread of the importation is, however, very rapid and in 9 years, seven-eighths of the females born carry some imported genes.

So far we have been dealing only with females registered in a given year. However, in the parents of those females we have a sample of the mature animals breeding at the time. The proportion of imported blood in the sires and dams of registered females is shown in Table 5.

TABLE 5. *Percentage of Imported Blood in Breeding Stock*

Year	*Sires*	*Dams*
1938	11·6	0·8
1940	22·8	2·8
1943	33·7	7·1
1945	37·3	10·9
1947	40·3	16·1

The proportion of imported blood in the sires is rather higher than would be expected from that in the males registered. This is the second stage in the selection of sires. The first selection is at registration, as was seen in Table 3. But registered males have not all equal chance of becoming sires and there is further selection between registration and use. To take the females born in 1943 as an example, their sires carry

[1] In an earlier publication [2] this figure was erroneously given as 10·3 per cent., which is in fact only the contribution as far as the grandparental generation.

on the average 33·7 per cent. of imported blood. Taking the average age of the sires as 3–4 years, the percentage of imported blood in their registered male contemporaries is about 17 per cent., whilst that in their female contemporaries is about 9 per cent.

The dams in Table 5 are, of course, the population of milking cows at the time. As their average age is around 5 years, it is to be expected that the figures for imported blood in adult cows will lag about 5 years behind those for registered female calves. We may check the assumption that there is little selection possible on the female side by calculating, from the observed distribution of the ages of dams in 1945 and the proportion of imported blood in females born in previous years, the expected proportion in dams in 1945. The figure obtained, 11·8 per cent., is certainly well within sampling error of the observed 10·9 per cent.

We may further analyse the figures for registered females according to the source of the genes in the importation. Several of the females in the 1936 importation were in calf on importation, and they gave birth to 13 bull calves and 12 heifer calves. The genes deriving from these animals were in the estimation of the 'maximum reproduction factor' considered as being from the cows themselves. In this analysis they are presented separately as 'carried in cows'.

TABLE 6. *Percentage of Genes in Registered Female Calves deriving from the* 1936 *Importation*

Year	*Bulls*	*Cows*	*Carried in cows*
1938	5·9	0·2	0·1
1940	11·1	0·8	0·7
1943	16·7	2·6	1·1
1945	18·8	3·6	1·7
1947	20·1	5·6	2·5

The influence of the bulls is at the start very much greater than that of the cows, but the latter catch up to some extent. Almost all the early matings of imported cows were to imported bulls, giving progeny with 100 per cent. imported blood and therefore equivalent to the imported animals themselves.

In the purchase of the 1936 importation, particular attention was paid to butter-fat percentage, which was thought to be one of the main failings of the British Friesian breed at that time. As fat-percentage is less affected by management than is yield, we can get an approximate measure of the genetic improvement from the yearly averages for the breed. It would have been of interest to follow the change as the percentage of imported blood in the adult cows increased, but unfortunately no figures are available for the period 1937–47. In the 4 years 1934–7 inclusive, the average fat-percentage was 3·28 per cent. (from Ministry of Agriculture figures) and in the years 1948 and 1949 it was 3·44 per cent. [3*a*]. For other breeds the figure remained constant or even declined slightly. This improvement is almost certainly genetic, although

some improvement may be due to the Register of Merit scheme, for entry into which cows need a fat-percentage of 3·50 per cent. The cows milking in 1948–9 would be expected to carry about 22 per cent. of imported blood. A further check can be got on this from the progeny-test lists published in the M.M.B. Annual Report, 1949 [3*b*]. The group of 148 bulls in the list are selected on the average yield of their daughters, so there was probably little selection on fat-percentage. The correlation between the percentage of imported blood carried by the sire and the fat-percentage of his daughters was 0·35 and the regression was 0·0020. At the two extremes a group of 47 bulls with no imported blood had daughters averaging 3·39 per cent. fat, and 7 bulls with 100 per cent. imported blood had daughters averaging 3·6 per cent. From this result, which is probably more reliable than the previous figure as a measure of the genetic level of the imported stock, cows with 100 per cent. imported blood would give on the average 0·40 per cent. more fat than cows with no imported blood.

Important herds and animals.—The proportion of lines tracing back to any animal measures its importance in the development of the breed. This does not, however, give an estimate of its average genetic relationship to members of the breed but only the direct relationship through its progeny. An animal can have a high over-all relationship to the breed as a whole without being of any direct importance itself, as for instance the full-sib of an important bull. The results are given in Table 7 for

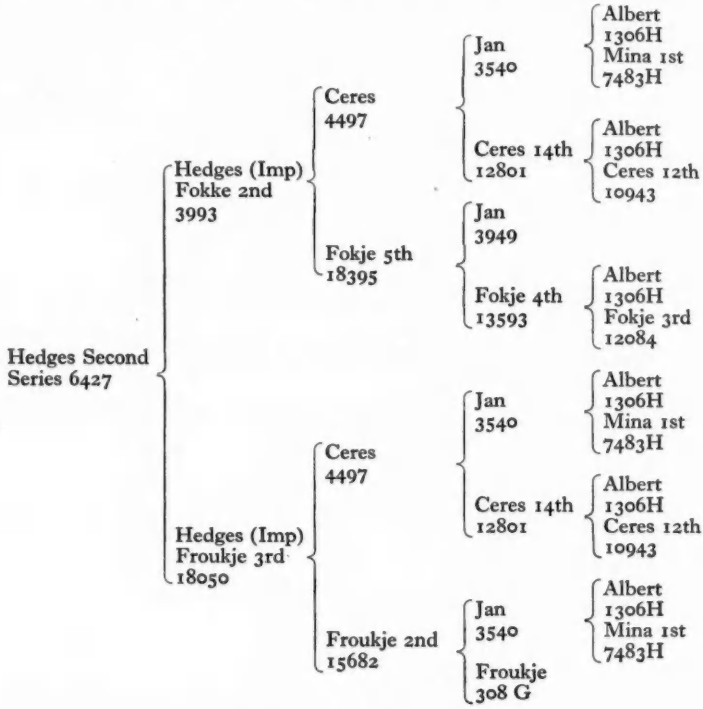
TABLE 7. *Per cent. Direct Relationship of Animals Important to the Breed*

Name and herd-book no.	*Registered females born in*				
	1917	*1924*	*1931*	*1938*	*1945*
Hedges Tatton King 321	3·3	1·4	1·9	0·9	0·8
Beccles (Imp) Lodewijk 3501	1·0	1·1	2·7	3·3	1·4
Cradlehall (Imp) Hollander 3737	0·9	1·1	1·6	2·7	2·3
Dunninald (Imp) Cesar 2nd 3813	0·4	1·1	1·6	3·1	2·3
Hedges (Imp) Fokke 2nd 3993	0·4	1·7	3·1	2·9	2·8
Kingswood (Imp) Ynte 4047	0·3	2·8	2·3	1·4	0·8
Terling (Imp) Vic Bertus 4541	0·7	1·6	3·0	1·6	0·8
Hedges (Imp) Froukje 3rd 18050	0	1·4	2·7	2·1	2·2
Hedges Second Series 6427	..	1·2	5·0	3·6	3·8
Hache Cerjan Ulysses 14165	..	0·2	2·2	2·7	3·0
Terling (Imp) Marthus 21533	..	0·3	0·8	4·8	5·9
Royal (Imp) Hiltkees 46907	..	..	..	0·1	2·5
Ceres 4497 F.R.S.	1·4	3·5	6·8	7·4	6·6
Albert 1306H F.R.S.	2·9	6·1	8·5	8·0	7·7

All bulls except Hedges Froukje 3rd.

the different years for those animals whose direct relationship in any year was more than 2·5 per cent. As might be expected, the majority of animals in the list were imported. Dealing with the animals in order of appearance, the first bull, Hedges Tatton King, born in 1905, is the only representative of the foundation stock. He had already been used considerably before 1910 and there are many of his progeny in the first

herd-book. The next 7 animals, 6 bulls and 1 cow (Hedges Froukje 3rd), were all imported in 1914 and for none of them is the direct relationship to the breed ever more than 3·3 per cent. The next bull, Hedges Second Series, is the son of Hedges Fokke 2nd and Hedges Froukje 3rd and is moderately inbred (F = 0·203) as can be seen from his pedigree.



He was, however, proved in an unrelated herd. He was born in 1916, and now ranks second in importance, having in 1931 a direct relationship to the breed of 5 per cent. Hache Cerjan Ulysses, born in 1920, is his son.

Although the 1922 importation as a whole had smaller influence than the others, it did contain the most important member of the breed, Terling Marthus. Although of South African stock, all the lines in his pedigree trace back to animals in Holland around 1910. He is three-sixteenths related to Ceres 4497, the double grandsire of Hedges Second Series, and though his influence was small in 1931 it increased rapidly during the thirties and was accelerated by the sale of some of his inbred sons out of his own daughters. He now contributes 6 per cent. of the genes in the breed and is therefore virtually the great-great-grandfather of the breed. Royal Hiltkees is the only animal of the 1936 importation so far represented.

The earlier importations were to some extent related both within themselves and with each other. The 1914 importation was fairly closely related to the bulls Ceres 4497 and his double-grandsire Albert 1306H. The blood of these bulls was also present in the 1922 importation and, naturally, in the 1936 importation from Holland. Unfortunately it proved impossible to get full pedigrees for all animals in the 1922 importation, although they were obtained for the important animals in the Terling herd. Similarly, although the pedigrees of the 1936 group are given in fair detail in the 1935 herd-book, a small proportion of the lines does not go sufficiently far back. The last 2 lines in the table show the direct relationship (as far as it could be ascertained) of Ceres 4497 and Albert 1306H to the breed. The true figure is probably not more than one-quarter higher in either case. We have therefore the odd result that the 2 animals who have still the highest individual relationship to the breed are 2 bulls which never left Holland.

The time taken for an important animal to exercise his full influence seems, as in the case of the spread of the importations, to be of the order of 10–15 years. Hedges Second Series has his maximum effect in 1931, 15 years after his birth, and the influence of Terling Marthus is still increasing, although most of the rise had taken place by 1938, 16 years after his importation.

One cannot attach any simple meaning to the proportion of lines that trace back through given herds, but at least it does give a rough measure of the importance of the different herds in the development of the breed. The results are given in Table 8 for those herds with more than 5 per cent. of lines in any period. It should be remembered that a line may

TABLE 8. *Percentages of Lines tracing back through Important Herds*

Herd	*Founded*	*Dispersed*	*1917*	*1924*	*1931*	*1938*	*1945*
Terling-Lavenham	..	..	7·8	12·3	10·0	14·5	17·1
Hedges . .	..	1932	11·1	8·6	12·6	8·3	7·5
Dunninald . .	..	1922	1·2	4·5	5·5	6·4	3·6
Colton .	..	1919	6·2	5·8	3·7	3·0	3·0
Kingswood . .	..	1948	0·6	5·3	6·1	3·6	4·9
Knebworth . .	..	1930	4·9	6·5	1·1	2·7	2·3
Clockhouse . .	..	1922	0·6	2·8	3·7	5·6	3·1
Hache. . .	1919	1928	..	0·6	7·5	9·4	6·9
Royal . . .	..	..	0·8	0·6	2·0	4·5	6·4
Douneside . .	1918	..	..	0·6	3·1	4·7	6·1
Hales . . .	1921	..	..	0·1	1·1	2·7	5·3

trace back through several herds and will, of course, be credited to all of them. Dates of origin and dispersal of the herds are also given, no entry indicating that a herd either existed at the start of the herd-book or still exists at the present time. Only 2 herds in the list, Terling-Lavenham and Royal, have existed over the whole period. The Terling-Lavenham herd, in first place in 3 of the 5 periods, is by far the most important of the herds still extant. It has always had a great influence on the breed, partly because of its own large size (it registered about 400 heifer calves

in the 1947 herd-book) and because of its breeding-policy. It has been kept fairly closed except for the imported animals, and the bulls in those have always been used in moderation until their merit was known. At present about 25 per cent. of the lines in the herd trace back to the 1936 importation and about 25 per cent. to Terling Marthus. He is effectively the grandfather of the herd. Animals in the herd are on the average about 3 per cent. inbred, mostly to Marthus.

To find out more about the structure of the breed in its dependence upon the leading herds, a survey was made of the herds from which sires were bought. In the more recent period over 80 per cent. of the sires were bred in herds other than the one in which they were used. A large sample of registered females was taken from the 1945 herd-book and their sires tabulated. The second stage was the tabulation of the sires used in the herds in which the first group of sires were bred, and so on. It was found that after 2 stages there was little change in the herds represented. The breed is therefore in roughly 3 levels. The top level is a group of 20–30 herds, in which the sires derive mainly from within the group. In this group, the Terling-Lavenham herd is the first among equals; its bulls are sold to the other members of the group, but few are bought in. This top group then sells bulls to the middle group, which in turn sells bulls to the bottom group. As a result, over 80 per cent. of the paternal grandsires of the females born in 1945 were bred in herds in the top group. The bottom group presumably sells bulls to the non-pedigree Friesian herds. The top group are mainly those herds which brought in bulls in the 1936 importation. The actual structure is, of course, not as rigid as this, and there are some herds that it would be impossible to place exactly, but the picture is roughly correct.

As so many sires are bought from other herds and little improvement is possible by culling females, it follows that the great majority of breeders are relying on somebody else to do their job for them. All the groups keep in step behind the top group, and the top group has to continue to progress in order to keep on top. The genetic superiority which the top group may possess at any time is continually being reduced by the use of its bulls in the middle group, and so on. The rest of the breed is being graded up to the top. If the system were rigid and the top group were improving genetically at the rate of x gallons per generation, it is not too difficult to show that the middle group will keep in step $2x$ gals. behind the top, with the bottom group another $2x$ gals. behind it. As x is hardly likely to be more than 20 gals., the probable difference between top and bottom groups would be around 80 gals. This observed structure agrees well with the results on the spread of the influence of an importation, when it was found that in 10 years (2 generations) about 90 per cent. of all females born carried some imported blood.

In addition to the differences between herds due to their relative positions in this system, there will be a further random variation arising from the small number of bulls used in a herd at any time. The genetic level of any herd will then vary as the individual bulls used are better or worse than usual. We can get a measure of the resulting extra varia-

tion between herds from the average genetic relationship between contemporary cows in the same herd. The higher the genetic relationship within herds the greater will be the genetic variation between herds, or, in other words, the more alike are cows in the same herd, the more obvious will be the differences between herds. In fact, the extra variance component between herds is equal to the mean genetic relationship between cows milking at the same time multiplied by the total genetic variance. We therefore calculated the average relationship between the dams of the sample of 80 heifer calves in 1945 and another cow chosen at random calving in the same herd in the same year. The average relationship was 7 per cent., the greater part of which came from pairs of cows having the same sire. This figure may seem rather low, being equivalent to the relationship between animals having one grandsire in common. The low value derives from the wide spread in age between cows milking at the same time and the habit of buying in bulls from other herds. Picking pairs of cows in the same herd at random, only in one-quarter of cases will they have the same sire. The genetic variance between herds from this source will then be 7 per cent. of the total genetic variance. As an estimate of the genetic standard deviation for yield we may take one-tenth of the average yield, a figure derived from heritability studies within herds. The standard deviation of the herd average breeding-value due to the genetic relationship within herds will be roughly $0{\cdot}10 \times \sqrt{0{\cdot}07}$, or about 3 per cent. of the average yield of the breed.

Previous work on the migration of breeding stock [2] has suggested that there is little likelihood of any regional differentiation within the breed. The two factors discussed above—the stratification of the breed due to the method of buying bulls and, superimposed on it, a random variation due to the small number of bulls used at any time—include the greater part of the genetic variation between herds. The total genetic differentiation between herds is therefore not very great: for yield a probable separation of the top group from the mass of the breed of less than 100 gals. and a random component with a standard deviation of about 3 per cent. of the average yield, or less than 30 gals.

Amount of inbreeding.—An obvious problem in the analysis of the inbreeding arises from the relationship both within and between the different importations. It is necessary, in order to give meaning to the inbreeding coefficient, to take as zero the population at some given time, such as 1910; but shall it refer to the breed in England at that time or in Holland? As a point of attack, it was assumed that the inbreeding would be referred to animals registered in the 1910 herd-book, and that the importations would be considered as unrelated both within themselves and to each other.

The over-all inbreeding averaged over the whole population may conveniently be divided into three parts: the current inbreeding, due to relationships in the parental and grandparental generations (sib or parent-offspring matings); the long-term inbreeding due to the relationship of important animals to the whole breed; and the remainder, corresponding roughly to the separation into strains within the breed. In

the actual estimation of the total inbreeding, distinction was made only between current inbreeding, estimated on a large number of matings, and the 'non-current', estimated from the 8-line pedigrees after omission of the current inbreeding in them.

The extent of current inbreeding varied little in the different periods. The results are given in Table 9, which shows the number of registered females sampled and the number of sire-daughter or half-sib matings, the only two types found. The number sampled in each period was rather arbitrary.

TABLE 9. *Current Inbreeding*

Year	*Matings in sample*	*Sire-daughter*	*Half-sib*	*Current inbreeding, %*
1917	441	2	15	0·54
1924	1,085	7	38	0·60
1931	1,014	7	44	0·71
1938	704	1	22	0·43
1945	698	2	18	0·40

Of the total of 3,942 matings sampled, 19 were sire-daughter and 137 half-sib. Over this period, therefore, about 1 mating in 200 was sire-daughter and 1 in 30 between half-sibs.

In the estimation of the 'non-current' inbreeding from the 80 eight-line pedigrees, each animal had a possible 16 ties, so that the total number of ties had to be divided by 80×32 to obtain the average inbreeding.

TABLE 10. *Total Inbreeding*

Year	*Current %*	*Non-current*		*Total, %*
		Ties	*Inbreeding, %*	
1917	0·54	..	0·17	0·71
1924	0·60	4	0·16	0·76
1931	0·71	29	1·13	1·84
1938	0·43	31	1·25	1·68
1945	0·40	21	0·81	1·21

As the 1917 pedigrees were drawn out completely, the figure given is merely the average amount of non-current inbreeding found. The standard error of the estimate of total inbreeding is around $\pm 0{\cdot}25$ per cent. for the last three periods and smaller for the first two.

The final component due to the concentration of the whole breed on few ancestors can be calculated from the average relationship of possible mates, chosen at random, usually termed the '*inter-se* relationship' within the breed. The long-term inbreeding is then equal to one-half of this, or more exactly $\frac{r}{2-r}$. In this analysis the sample of animals in each period was divided into 2 groups of 40 in order to obtain a measure of the sampling error of the final estimate. Within each group the average

relationship of each sire to every other dam except his actual mate was calculated. In each hypothetical mating there are 16 possible ties, and there are 40×39 matings, so that the total number of ties must be divided by $40 \times 39 \times 16$ to estimate the average relationship. A rough measure of the standard error can be obtained from the 2 estimates for each period.

TABLE 11. *Average Genetic Relationship between Animals drawn at random from the Breed*

Year	Inter-se *relationship*	*Resultant expected long-term inbreeding*
1917	0·18 per cent.	0·09 per cent.
1924	0·39 ,,	0·20 ,,
1931	0·94 ,,	0·47 ,,
1938	1·07 ,,	0·54 ,,
1945	1·13 ,,	0·57 ,,

The standard error of the estimate of relationship is $\pm 0{\cdot}12$ per cent. for the last three periods and less than that for the first two.

Comparison of the above expected inbreeding with the 'non-current inbreeding' from the same animals shows that the final component corresponding to strain-differences is not large, being at the highest 0·66 per cent. in 1931.

The removal of the assumption that the importations were unrelated and the carrying back of all pedigrees to about 1905 gives for the females born in 1945 18 extra ties or a total extra inbreeding of 0·70 per cent. This is probably a slight under-estimation because of the impossibility of carrying some of the lines sufficiently far back, as mentioned above. Of the extra ties 12 were from relationships within the 1914 importation and 2 within the 1936 importation. Of the remaining 4, 2 were from relationships between the 1914 importation and the 1922, and 2 between the 1914 importation and the 1936. It seems, therefore, that the common ancestors in the different importations occurred too far back in the pedigrees to contribute greatly to the inbreeding, and that the successive importations are effectively outcrosses, which keep the measured inbreeding low.

In the course of the work on current inbreeding, the ages of parents at the birth of their offspring were tabulated. The means were as follows for animals born in 1945:

Age of sires of registered females . . .	3·76 years
Age of dams of registered females . . .	5·06 years
Age of sires of registered males . . .	4·12 years
Age of dams of registered males . . .	5·52 years

The mean of these, 4·61 years, can be taken as the effective generation length. On the average the parents of registered males are older than those of females. This result could be obtained by the deliberate selective registration of bulls from the older cows with several records by older

bulls with progeny records. However, examination of the distribution in detail shows that the selection was particularly in favour of dams born in 1937 and 1938 and of sires born in 1938. This suggests that the selection is mainly for sires and dams that are offspring of the imported animals. Only 12 per cent. of sires were more than 6 years old at the birth of their daughters. Buchanan Smith, and Robison [4], in an analysis of the age at calving of 4 dairy breeds, found a mean age of 5·49 years. However, in their analysis they combined the data for bull and heifer calves, which on our results would give an average of 5·29 years.

The grading-up system.—Although the scheme started in 1921, the numbers remained small until 1935: in the early thirties the annual registration in the D grade was around 200 animals, compared with about 5,000 females in the full herd-books. There was a general expansion starting about that period, and in 1949 there were about 2,200 females registered in the D grade and 21,349 in the full herd-book. As the number in the D class has generally been less than 5 per cent. of the number in the full herd-book, it is not surprising that the scheme has had little effect: in 1947 only about 0·4 per cent. of the genes in the breed had been derived from A-grade non-pedigree cows. Nor has the process of expansion been greatly aided by the grading-up system. It is hoped to deal more fully with the dynamics of expansion in another paper, but it seems that of the 21,000 female registrations in the full herd-book in 1947, compared with 5,000 in the 1935 book, only 2,600 owe their existence to the grading-up system.

We may consider the grading-up scheme theoretically against the background of two possible extremes of breed-structure. In the first, we shall assume that animals in the full herd-book carrying outside blood derived from the grading-up system are bred from on exactly the same footing as pure pedigree animals. Then the amount of outside blood in the herd is continually increasing by the inclusion of D-grade animals as the dams of heifers. Let the number of females in the D-grade be a fraction x of the number in the full herd-book, where x is small. The frequency of outside genes in them will be $\frac{1}{8}$, as they have had 3 top-crosses. The increase in outside blood in the dams of cows will therefore be $x/8$ per generation. But the dams of cows contribute only one-fourth of the genes in the whole breed, and so the amount of outside blood in the breed will increase at $x/32$ per generation or roughly $x/160$ per year. If $x = 0{\cdot}05$, as it has been roughly for the Friesian breed, this would mean an increase of 5/160 per cent. or 0·03 per cent. per year.

At the other extreme will be a breed in which all bulls were bred in a central group of herds not taking part in the grading-up scheme. The genes in the breed already are diluted in each generation by the use of 'pure' sires, and a point of balance is reached where the introduction in each generation is exactly equal to the loss by dilution. This point is reached when the amount of outside blood in registered females at any time is equal to twice the rate of introduction per generation. Now the rate of introduction into registered females is $x/16$ per generation, so

that the point of balance is about $x/8$. For the Friesian breed, with $x = 0{\cdot}05$, this means a balance with 0·6 per cent. of outside blood in the breed.

Fig. 2, derived from the D-grade registrations and the observed reproductive rates, shows the expected percentage of outside blood on the two models. The graph for no discrimination against animals with grading-up blood shows the expected gradual rise of about 0·03 per cent. per year. The lower graph breaking away from it around 1939 (about

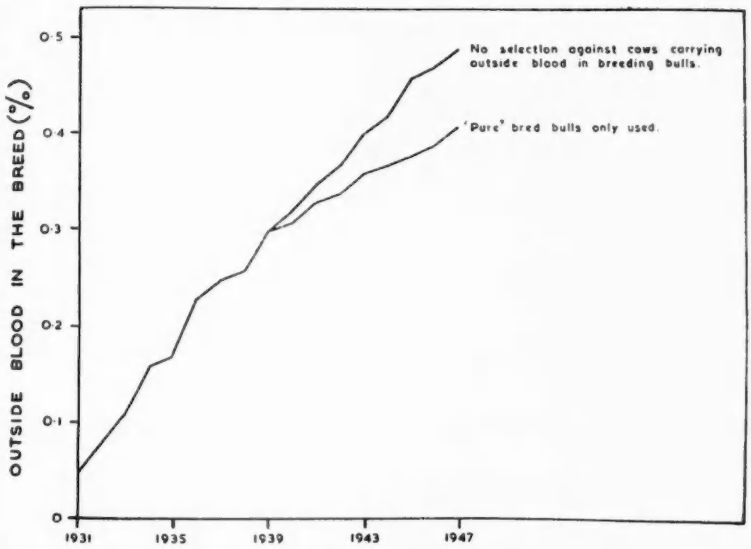


Fig. 2. The percentage of genes deriving from A-grade non-pedigree cows in registered heifer calves.

the first year that bulls carrying grading-up blood could possibly produce offspring) is the expected percentage on the assumption of the use of pure bulls only. Any actual estimation of the true level is rather arduous, but it presumably lies between these extremes. Pedigree investigations show that the sons of cows with grading-up blood in them have a smaller chance of being used than bull calves out of 'pure' dams. The dams of bulls used in 1945 had on the average only 0·10 per cent. of outside blood in them compared with 0·25 per cent. in their contemporaries. In the bull-breeding herds grading-up has not been used to any extent, so that this result is not altogether unexpected. The true point for 1945 is therefore rather closer to the lower line than the upper, giving a probable percentage of outside blood of about 0·4 per cent. Looking into the future, it is unlikely that this percentage will increase markedly so as to swamp the whole breed. One might predict with good chance of success that in 1960, assuming the grading-up system main-

tains the same size relative to the whole breed, the proportion of outside blood will not be more than 0·6 per cent.

We have been dealing with the genes introduced into full-pedigree animals and deriving from A-grade cows. It must not be assumed that the A-grade cows do not contain any blood derived from pure-bred animals. Some are registered as being by pure-bred sires, and even those registered on inspection as 'parentage unknown' can hardly help at the present time having some genes derived from pedigree animals. The above figures, small though they are, are certainly an over-estimate of the lines not tracing back to full-pedigree animals, if the ancestors of the A animals were known.

Discussion

Probably the most interesting aspect of this investigation is the light that it has thrown on the structure of the breed in terms of the individual herds. The general policy of buying-in a very high proportion of the bulls used, imposed largely by the small size of many herds, has the most important effect of continually levelling out genetic differences between herds. The interchange of bulls is not at random but is a directional process. We may picture the whole breed as roughly divided into 3 groups of herds. The top group, of some 20 to 30 herds, is fairly self-contained in that the interchange of bulls takes place mainly within the group. From it are sold bulls to a middle group of herds in which the genes carried by these bulls are multiplied and so enable the sale of the resultant male progeny to the rest of the herds. It is difficult to give any exact size to this middle group or to specify whether a given herd is a member of it, but it may be looked upon as containing roughly 100 to 200 herds. From the bottom group, the remaining 1,800 herds in the breed, bulls are sold for non-pedigree herds of the Friesian type.

By this process the top group of herds, by their very success in being able to sell their bulls, are all the time losing any genetic superiority they may have. The whole of the rest of the breed is being gradually graded up to the level of the top herds and the top group can stay on top only by continued genetic improvement. Calculations based on this model would suggest that, from the probable rates of genetic improvement in the top herds, the genetic difference in yield between the top and bottom groups is probably less than 100 gals.

There is, however, undoubtedly considerable variation between the level of production in different herds. Reports of the Milk Marketing Board indicate that there is almost as much variation between herds as there is between cows in the same herd. If, as the present study suggests, little of this variation is genetic, it must be due mainly to differences in management. Unpublished data on the performance of daughters of the same bulls in herds at widely differing levels of production would support this view. This has a bearing on the general problem of progeny-testing, especially if all the progeny of a bull are milked in the same herd. The average yield of his daughters is then a measure rather of the management-level of the herd than of the breeding value of the bull.

As a consequence of this breed-structure, the effects of an importation of breeding stock are very rapidly spread throughout the breed; but the two are not quite so simply related as cause and effect, and it could be argued that if this stratified type of breed-structure did not already exist, the policy of importation would have created it. Any herd containing an imported bull almost automatically moves into the top group. However, work on other breeds in which there is no importation shows a structure substantially the same. As a result of the several importations since 1914, only one-sixth of the genes at present in the breed derive from the foundation stock: the greater part of the remainder trace back to animals born in Holland in the last 40 years.

It is interesting to speculate on the possible effect of a further importation. In a sense, a policy of continued importations is a confession of failure on the part of the British breeder. The 1936 importation has undoubtedly increased the fat-percentage of the breed and a further importation will probably continue the process, although rather more slowly, as the genetic level approaches that of the breed in Holland. It is in its effect on the general technique of breeding that the policy would seem to be an unfortunate one. As the position stands at the moment, a breeder has little incentive to improve his herd genetically by the necessarily laborious methods of progeny-testing. He must realize that the simplest way to establish a fashionable bull-selling herd is to buy himself a bull out of the next importation.

At the present time the conditions that the new importation faces are rather different from those in 1936. The breed has quadrupled in size, but the introduction of artificial insemination on a large scale has greatly increased the scope of the individual bull. The effect of the change in numbers of the breed may not be very great. In the last resort, the importance of the importation to the breed depends on its effect on the top group of herds, and this will have changed little in size. The result of the wide expansion of artificial insemination is more uncertain. At present it is being used mostly in non-pedigree herds. Figures are available only for the Shorthorn breed in which, in 1948, only 3·8 per cent. of the females registered were produced by artificial insemination. As the sires used in A.I. are generally from the top group of herds, this represents, as it were, a short-circuiting of the usual process of bull-buying, and constitutes an even more effective method of grading-up the non-pedigree herds. In fact, the situation is such that in a generation or two the non-pedigree herds might be superior genetically to the general mass of pedigree herds. In hastening the spread of an importation within the pedigree herds, A.I. may, however, not play a very large part unless the bulls in use at A.I. stations become at all fashionable as the sires of bulls.

The grading-up system, used mostly by the bottom group of herds, has naturally very little effect on the breed as a whole. The impression is current in some circles that the breed has been swamped by animals deriving from the grading-up scheme. In fact, in 1947 only about 0·4 per cent. of the genes in the breed derive from A-grade non-pedigree cows, and the probable future rate of increase is around 0·03 per cent. a year.

Summary.—1. A survey of the breeding-structure in the British Friesian breed has been made by a pedigree-sampling method.

2. The effect of the various importations since the start of the herd-book in 1910 has been very large, so that at the moment only one-sixth of the genes in the breed derive from the foundation stock.

3. The degree of inbreeding, referred to 1910 as zero, has never at any period risen above 2 per cent. Correspondingly, no individual animal is highly related to the breed as a whole. The two animals with the highest direct relationship to the breed at the present time are bulls used in Holland before 1910.

4. The grading-up system, started in 1920, has had very little effect. In 1947 about 0·4 per cent. of the genes in the breed derive from non-pedigree cows registered in the A grade, and this figure will only rise slowly. As some of these A-grade cows will certainly have pedigree ancestors, this figure of 0·4 per cent. over-estimates the influx of completely foreign genes into the breed.

5. The breed seems roughly divided into three levels. From the top group of 20–30 herds bulls are sold to a larger middle group, and thence to the remainder of the breed. Over 80 per cent. of the paternal grandsires of all heifers born in 1945 are bred in this top group of herds. The consequences of this breeding-structure on the genetic variation between herds and on breeding policies in the breed are discussed.

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THE MENOUFI TYPE OF BUFFALO: A SUGGESTED SCORE-CARD

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DOMESTIC buffaloes originated from the wild buffaloes of India, and it is almost certain that the Indian buffaloes were first introduced into Egypt some time during the ninth century. The animal adapted itself very quickly to the climatic conditions of Egypt and occupied a very prominent place among its livestock.

The buffalo is the main dairy animal of Egypt. It gives far more milk than the native cow, with fat ranging from 6 to 9 per cent. Young buffalo males are used for veal production, the flesh being finer, firmer, and superior to that of the native cattle beef. In addition, most of the farm work is done by the buffalo, especially on the small holdings.

The writer selected the Menoufi breed for this study partly because the type is more distinct, and partly because of the characteristics of the Menoufia Province, which are the high fertility of the land and the large number of small holdings. The study is accordingly restricted to buffaloes of the Menoufi breed as bred and raised in the Menoufia Province. The 1947 figures for Menoufia Province show that there were 13·6 head of buffalo per 100 persons in the population and 0·47 buffaloes per feddan (acre) as compared with 6·5 and 0·21 respectively for the country as a whole.

The object of this work was to ascertain the conformation characteristic of the Menoufi buffalo, in order to: (1) prepare for the compilation of a suitable score-card for this breed; and (2) to distinguish between this and the other two breeds of buffaloes in Egypt, once score-cards for the other types have been established through similar work.

Two hundred adult females formed the basis of this study. All these were at least in their third lactation though a few were somewhat older. They were chosen at random from ten different parts of the Province.

Twenty-three measurements were made between various parts of the body. These are illustrated in Figs. 1 and 2.

Care was taken to have the animal stand in a nearly normal position on a level. Most of the measurements were taken twice or more in case the animal had changed its position, and the averages of the repeated measurements were used in the study. The writer devised a special instrument with a vertical and a horizontal arm for measuring the animals. A 50-cm. graduated bar and a 3-metre tape were also used in measuring the body-girth and the like.

The statistical study of the figures obtained showed that the deviation of any character in question from its mean was small and insignificant. A certain degree of homogeneity was found among the group. This was probably due to the use of few sires. The system of farming and type of environment by influencing selection in that direction which suited the

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Menoufi farmer most, also reduced the differences within that group to a noticeable degree, especially where conformation and size were concerned. The means (in centimetres) of the 23 points studied should represent the type in question; head-length 50·59, body-length 149·87, neck-length 51·41, length of pelvis 48·51, height at withers 134·28, front width of pelvis 55·78, hind width of pelvis 37·77, body-girth 234·65.

Taking as 100 the length of body from shoulder-point to the end of the pin-bone, the relation between it and other measurements was

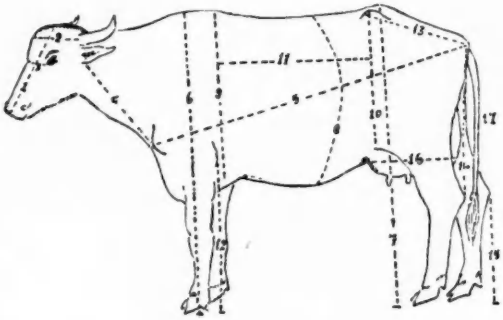

FIG. 1

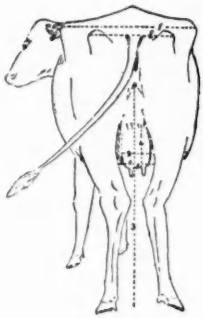

FIG. 2

FIG. 1. A profile illustrating 17 points: (1) Head-length. (2) Distance between horns. (3) Distance between eyes. (4) Neck-length. (5) Body-length. (6) Height at withers. (7) Height at hips. (8) Girth at the last back-rib. (9) Depth of chest. (10) Depth at flank. (11) Length between 9 and 10. (12) Height of elbow. (13) Length of pelvis. (14) Length between pin-bone and hock. (15) Height of hock. (16) Length of udder. (17) Tail-length.

FIG. 2. A rear view illustrating 6 points: (1) Front width of pelvis, across hips. (2) Hind width of pelvis, between pin-bones. (3) Height of hind legs, from point of rear attachment. (4) Height of udder. (5) Breadth of udder. (6) Width between thighs.

calculated to be: length of head 33·75; length of neck 34·29; height at withers 89·58; girth at last back rib 156·57; length of pelvis 32·35; depth at flank 44·45.

A comparison between the Menoufi buffalo and the Friesian cow from the point of view of measurements representing size and shape showed that the buffalo was shorter in body and rump, but the body-height, depth of chest, and width of pelvis hardly differed. The wedge-shape in the Menoufi buffalo was not so clear as in the dairy breeds.

In general the Menoufi buffalo is of medium size, shorter than the Beheri in body-length, though nearly of the same height. When mature the average weight of the cow is 1,360 lb. She is of an open conformation, generally of a milking type. The skin is usually thin, blackish-grey in colour with few hairs. The horns are comparatively small, usually curving backward, parallel to the neck, and remain almost on a level

with the poll. Their tips may bend slightly upwards. These horns are locally known as 'Egyptian horns'.

In accordance with the relative importance of the different points of the body a suitable score-card for buffalo of the Menoufi type is suggested. If faithfully followed by the breeders it should eventually lead to the elimination of most of the defects of that type. The suggested score-card is summed up as follows:

General appearance: A symmetrical balancing of all parts, proportional to each other, with general appearance of a high-class animal and a high capacity of food and productiveness at pail	10
Head, feminine in appearance, fine in contour; forehead broad between horns with no dishing; face of medium length, clean cut and trim, showing facial veins; muzzle broad; lips strong, usually wet, dark in colour; nostrils large and open; ears of medium size, fine texture, fringed inside with light-greyish skin; eyes large, full, mild, and bright	9
Horns, of comparatively small size, slaty in colour, of characteristic shape (the Egyptian horns)	2
Neck, of ample length, fine, neatly joined to shoulders and to head, free from loose skin, showing concavity of both top and sides, with a short characteristic dewlap under the brisket	4
Shoulders, on the same level with hips, broad and full at sides, smoothly blending into body	3
Chine, rising above shoulder-blades, broadly developed with open vertebrae	5
Forelegs, long, straight, set well apart; shanks fine, joints firm	1
Chest, deep and wide, full between back and forelegs, full in the foreflanks, with least possible depression back on the shoulders	7
Crops, full and level with shoulders	2
Barrel, long deep, of wedge shape; ribs amply sprung and wide apart; abdomen deep and large, trimly held up	7
Hindquarters, deep, straight behind; thighs long and wide apart; hocks not crooked and of proportional height	4
Loin, broad; hips prominent and wide apart	5
Rump, long with roomy pelvis, slightly drooping downwards	5
Pin bones, well apart; the ischial arch deep and roomy enclosing the tail-head set deep in it	3
Legs and feet, proportional to size, nearly straight, squarely set under the body; feet round and solid, not to weave or cross in walking	2
Tail, large at base, tapering fairly to end, reaching the hocks or below, ending with a round tuft of hair	2
Hide, of medium thickness, loose and mellow; hair fine and few; colour ashy blackish-grey	7
Udder, capacious, flexible; quarters even, of good size, extending well forward in the front, broad and well held up	12
Teats, equidistant, well formed, well apart, of convenient size	2
Mammary veins, large, tortuous, entering very large or numerous orifices; milk-wells of good size	8
	100

This score-card for the Menoufi will certainly require reconsideration after some generations have been bred. It ought, however, to serve as the immediate objective of the breed. Long-term modifications will be required in respect of change of system of husbandry and other points of economic importance.

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THE CATION-EXCHANGE PROPERTIES OF THE BASALTIC DRIFT SOILS OF NORTH-EASTERN IRELAND

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THE only large area of agricultural soils in the British Isles derived from basaltic material is located in north-east Ireland where it occupies some 1,500 square miles. The results of a preliminary survey of these soils have not yet been published, but the available data show that their cation-exchange properties exhibit interesting peculiarities. It was thought that it would be of interest to record these results for comparison with data for soils derived from similar parent material elsewhere.

Experimental

Representative soil profiles from areas of different soil series were examined in the field and samples taken for laboratory analyses. [The general description of the soils will be published elsewhere.] The results reported here for total exchangeable cations were obtained by summating the individual cations. With the exception of hydrogen, these were determined by leaching with neutral normal ammonium acetate, as described by Schollenberger and Simon [1], followed by spectrographic analysis of the leachates as described by Mitchell [2]. It was found that the dilutions given by Mitchell were too small for the soils under examination in the case of exchangeable magnesium; a dilution twice as great as that recommended by Mitchell was employed. Calcium was determined chemically using standard potassium permanganate. Exchangeable hydrogen and exchange-capacity were determined by the method of Parker [3], the organic-carbon contents by the method of Walkley and Black [4].

In the tables which follow no attempt has been made to record analytical data other than those which were thought to be relevant to the cation-exchange properties. The location of the soils together with a brief general description of their field characteristics precede the analytical data in each case. Total exchangeable cations are given throughout in m.e. per 100 gm. of soil.

Discussion

The cation-exchange properties of soils have generally been considered to depend on the amounts of colloidal clay and humus present. On this basis several workers have calculated the relative cation-exchange capacity of these two fractions, but the results obtained in the present investigation show that it is difficult to reconcile the calculated values for exchange capacities of the clay and organic-matter fractions with generally

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TABLE 1. *Profiles S_B 1 and S_B 3*

Dark-brown fairly free-draining clay loams on medium thick boulder till. Ballyvesey, Co. Antrim

S_B 1

Depth, in.	*Total exchangeable cations*	*Exchange capacity*	*Clay + loss by sol., %*	*Organic carbon, %*	*pH*
0–5	35·86	38·8	40·2	10·0	5·57
5–9	35·80	36·6	39·7	9·2	6·05
9–13	37·41	35·4	11·10	2·4	6·07
13–23	31·32	30·7	11·3	1·32	6·18
23–32	29·73	24·8	11·4	0·52	6·20
32 and over	31·54	28·0	7·2	0·32	6·32
		S_B 3			
0–3	37·54	36·3	31·8	9·10	5·42
3–7	39·25	38·4	25·0	5·60	5·60
7–11	43·72	40·1	5·8	0·80	5·87
11–21	36·33	37·2	7·2	0·21	6·00

TABLE 2. *Profile S_B 4*

Dark peaty soil with impeded drainage due to ground-water on medium thick boulder till. Ballymartin, Co. Antrim.

S_B 4

Depth, in.	*Total exchangeable cations*	*Exchange capacity*	*Clay + loss by sol., %*	*Organic carbon, %*	*pH*
0–10	58·58	54·3	34·6	13·00	5·88
10–13	40·83	38·3	30·9	1·25	6·06
13–22	43·23	40·3	21·5	0·90	6·22
22–25	39·80	35·4	19·8	0·60	6·32
25–34	34·72	32·0	6·0	0·10	6·38
34 and over	31·35	30·0	7·3	0·10	6·42

TABLE 3. *Profile S_B 5*

Dark-brown free-draining loam on glacial sands and gravels. Doagh, Co. Antrim.

S_B 5

0–3	35·20	37·0	27·6	4·8	6·08
3–9	35·02	34·2	12·1	5·2	6·00
9–21	35·29	33·8	16·7	5·2	6·12
21–32	29·91	30·4	13·2	2·8	6·00
32–43	47·46	47·1	9·3	1·01	6·32
43–65	44·30	43·6	9·2	0·56	6·38

TABLE 4. *Profile S_B 6*

Dark-brown medium loam on mixed boulder clay and glacial sands. Clady Bridge, Co. Antrim.

S_B 6

0–20	35·92	35·2	38·2	7·00	5·63
20–25	50·70	46·4	38·4	3·01	6·32
25–33	58·15	51·2	27·7	0·76	6·44
33 and over	45·84	41·7	7·7	0·10	6·69

TABLE 5. *Profile S_B 7*

Dark-brown heavy loam with impeded drainage in subsoil layers on very deep boulder till. Shane's Castle, Co. Antrim.

S_B 7

0–9	40·45	43·2	33·4	6·0	5·81
9–20	45·93	49·4	21·0	1·5	5·95
20–35	45·96	46·5	10·8	2·0	6·13
35 and over	47·48	42·4	19·5	0·6	6·05

TABLE 6. *Profile S_B 8*

Similar to soil profile S_B 7. Massereene Park, Co. Antrim.

S_B 8

0–11	38·20	39·10	41·6	8·54	5·65
11–30	46·58	50·1	19·4	1·00	6·40
30 and over	49·90	53·5	15·8	0·60	6·71

TABLE 7. *Profile S_B 10*

Dark-brown clay loam with impeded drainage on deep boulder till. Tully, Killead, Co. Antrim.

S_B 10

0–9	46·13	42·2	34·0	5·40	6·18
9–18	48·46	47·3	28·0	1·52	6·57
18–44	49·07	47·7	16·8	0·30	6·91

TABLE 8. *Profile S_B 11*

Dark-brown clay loam, fairly free-draining on deep drumlin drift. Forthill, Ballymena, Co. Antrim.

S_B 11

0–9	52·77	49·8	29·9	6·00	5·88
9–12	53·35	49·9	18·6	3·01	5·83
12–21	48·62	49·5	15·4	1·21	6·10
21–28	48·14	48·8	8·8	0·42	6·20

TABLE 9. *Profile S_B 12*

Dark-red friable medium loam on deep morainic drift. Killagan, Co. Antrim.

S_B 12

Depth, in.	*Total exchangeable cations*	*Exchange capacity*	*Clay + loss by sol., %*	*Organic carbon, %*	*pH*
0–12	31·65	27·6	22·1	6·5	6·02
12–20	31·50	30·1	12·2	1·2	6·33
20 and over	29·99	27·8	8·9	0·4	6·88

TABLE 10. *Profile S_B 13*

Dark-brown medium loam with free drainage on shallow drift over hard basalt. Slemish, Co. Antrim.

S_B 13

Depth, in.	*Total exchangeable cations*	*Exchange capacity*	*Clay + loss by sol., %*	*Organic carbon, %*	*pH*
0–12	44·16	43·4	17·9	5·4	5·89
12–18	36·12	32·8	13·0	2·3	6·08
18–22	31·47	30·1	9·5	0·8	6·24

TABLE 11. *Profile S_B 14*

Dark-brown peaty loam with impeded drainage on shallow drift over hard basalt. Slemish, Co. Antrim.

S_B 14

Depth, in.	*Total exchangeable cations*	*Exchange capacity*	*Clay + loss by sol., %*	*Organic carbon, %*	*pH*
0–12	50·11	51·8	18·2	10·6	5·56
12–22	43·69	46·5	13·2	3·5	5·89
22 and over	42·42	46·6	9·7	2·8	6·09

accepted values. Mattson [5] has given figures for the exchange capacity of clays ranging from 0·16 to 1·1 m.e. per gm. of clay; and Williams [6] from calculations of the relationship of clay and organic-carbon content to the exchange capacity, found a value of 0·57 m.e. per gm. of clay.

For the lower horizons of the soil profiles under investigation, it is obvious that in most cases calculations of the cation-exchange capacity would result in figures as high as 5 m.e. per gm. of clay. Calculated figures reported by Mitchell and Muir [7] for subsoils of basic igneous origin were of an even higher order. Compared with recorded figures for the cation-exchange capacity of soils of similar clay percentage derived from different parent material encountered in the British Isles, the values found for the basaltic soils described are of a markedly higher order. Unpublished results relating to soils developed on other parent material in Northern Ireland have been collected by McConaghy [8], and these also show that the exchangeable-cation contents of the subsoil horizons are of a lower order than those of basaltic soils.

Robinson [9] suggested to the author that an investigation of the buffer curves of the various fractions of the soils would be of value in determining the relative contribution of these to the cation-exchange capacity. It has not been found possible to complete this work as yet, but curves for the surface soils have shown that the soils are strongly buffered

Mitchell [10] and Whelan [11] reported similar findings when working with an Inschfield basic igneous soil. The possibility that the coarser fractions of the inorganic portion of the soils are participating in cation-exchange is supported by the fact that there is little variation in the exchange capacity with depth. The general agreement between the exchange capacity and the sum of the exchangeable ions indicates that cations are held in a truly exchangeable form. Further, determinations of exchangeable ions by leaching with ammonium acetate is considered to give normal exchange values, since the monovalent ammonium ion does not form basic 'salts' with the exchange acids, and the monovalent acetate ion is not excessively absorbed, as are polyvalent anions [12].

Glentworth [13] quotes unpublished work by Mitchell and Muir to show that the rise in exchange-capacity in the lower horizons is due not to the clay fraction but to certain constituents of the sand fraction.

Recent work by Hosking [14] points out that recent work by Marshall and his colleagues has shown that the conventional methods of dispersion, as employed in the present investigation, do not separate all the clay minerals from the silt and sand fractions. Hosking has carried out an exhaustive study of the cation-exchange properties of the various soil fractions from soils of various geological origin, and gives data for a basaltic soil in which the sand and silt fractions contribute 40 per cent. of the total exchange capacity.

Through the courtesy of Dr. G. F. Walker of the Macaulay Institute for Soil Research, Aberdeen, samples of the clay complex from profile S_B 12 have been subjected to X-ray analysis. The results of these analyses showed that kaolinite was present in all horizons. A similar observation has been recorded by Hosking [14] for soils of basaltic origin in Australia. Since kaolinite has a relatively low cation-exchange capacity it would seem that the high capacity of the lower horizons of the profiles described could not be accounted for by the clay fraction alone. These findings would give added support to the view that the high exchange capacity might reside to a large extent in the fractions of greater dimensions. The presence of intermediate weathering products of vermiculite type, confirmed by X-ray analysis, might also account for the high values to some extent.

In most of the profiles of the different soils examined there is a tendency for the exchangeable magnesium figure to increase with depth, accompanied by a fall in exchangeable-calcium content without appreciable alteration in the figure for total exchangeable cations. The exchangeable magnesium contents of some of the subsoils are of the order of 14 m.e. per 100 gm. soil, and it has been found that these subsoils and some of the surface soils exhibit peculiar physical properties. On drying out, these soils tend to form stiff 'clods', a property of soils which has been associated by Mitchell [10] and by Joseph and Oakley [15] with a high content of exchangeable magnesium.

Since the cation-exchange capacity of these basaltic soils is of a high order, it would be expected that normal rates of liming would effect little change in pH. That this is in fact the case has been borne out by routine soil analyses over a period of years. Conversely, it has been

found that the base status is much more easily maintained in practice than with many other soils in the Province; a result in conformity with the observation of Mitchell [10] that the rapidity with which applied lime becomes exchangeable is an important factor in determining the extent of leaching.

Summary.—Exchange capacities, clay- and organic-carbon contents of soil samples from profiles of different soil series derived from basaltic parent material are presented; and the high values found for these soils are discussed in relation to mechanical composition.

The exchange capacities are considered in relation to soil reaction and the significance of the high exchangeable-magnesium content of some of the soils of characteristic physical texture is discussed.

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STUDIES ON THE ENSILAGE OF KALE

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THE ensilage of kale has been investigated much less than that of grass or cereal crops, and the chief reasons seem to be that kale is relatively easy to ensile and the product is obtained without the addition of molasses or acid. Nevertheless the losses associated with the process have always been assumed to be high, being of the order, as shown by Ferguson [1], of 33 per cent. of dry matter, 41 per cent. of nitrogen-free extract, and 34 per cent. of crude protein. Poijärvi [2] gives somewhat similar figures as a result of investigations carried out in Finland. Of variations which have been applied in order to reduce the losses encountered, mention may be made of the addition of straw as suggested by Ferguson [loc. cit.], the shortening in length of the chopped pieces as advocated by Hellberg [3], and the use of ammonium salts as described by Windheuser *et al.* [4]. To offset the losses associated with this particular process it has been suggested by Wood [5] and others that the yields of kale per acre in terms of starch equivalent counteract the economic losses of the ensilage process. Possibly the most complete work on the subject of kale ensilage is due to Edin and co-workers [6], but their results are not in entire agreement with those of other workers.

The present authors were interested in the problem of kale ensilage from several points of view. In the first place, it seemed desirable to consider exactly how the losses do occur and if they can be controlled. Secondly, as in the north-east of Scotland there is frequently frost when kale is harvested, it was wondered whether ensiling in frosty weather has a deleterious effect. The only relevant note in the literature on this subject is about frosted kale by Kirsch and Jantzon [7], who showed that the resultant silage tends to be of high pH. Lastly, by a process similar in effect to ensilage, though different in nature, the question arises, would partial sterilization with sulphur dioxide give a better product? The standard of success with regard to these questions is whether fermentation did in fact take place as judged by a fall of pH and the formation of lactic acid.

Experimental

It was decided to ensile approximately 2-cwt. portions in each of three cylindrical towers of inner dimensions 3 ft. by 1 ft. 9 in., similar to, except in size, those described by Barnett and Miller [8], and the effluents were collected as described by these two workers. As the towers were new, it was necessary to 'season' them by washing with sodium silicate solution and a week later to wash the silicated surface with very dilute sulphuric acid. Finally, at the end of 2 days the towers were washed with water till the washings were neutral. In Tower I the

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kale (89·70 kg.), chopped in the usual way, was ensiled without any additions; in Tower II a kilogram of molasses in 4 litres of water was added and uniformly mixed with the kale (109·70 kg.), and in Tower III sulphur dioxide was added by allowing the tower to fill with the gas from a syphon; a few kg. of kale were then sprinkled in and the filling with sulphur dioxide repeated till the tower was full. The weight of kale ensiled in this tower was 96·55 kg. The amount of sulphur dioxide added was about 43 gm. In each case the filling process was stopped at frequent intervals to permit a consolidation of the mass by means of a wooden 'bishop'. On the completion of filling, the mass was covered with a layer of sisalkraft paper over which sacking was laid. A closely fitting lid weighing 1 cwt. was then lowered into each tower and the towers covered with tarpaulin caps to exclude rain.

The effluents were analysed daily for volume, dry matter, pH, and nitrogen; and those from Tower III for sulphur dioxide. The process was regarded as complete after 28 days by which time the pH of the effluent had remained constant within narrow limits for some 10 days (Fig. 1) and the effluent flow had ceased. The towers were emptied and the total contents of each were weighed. After a very thorough mixing of each product, two biscuit-tinfuls of each were removed for analytical purposes and the balance set aside for a palatability trial.

Analytical methods used.—1. Nitrogen, pH, and dry matter were determined on the kale and on the three silages using the standard methods. The dry matter of the effluents was determined by evaporating 50 ml. to dryness on a water-bath after adding a few drops of concentrated hydrochloric acid. After drying for 1 hr. in the steam-oven the product was weighed and the total dry matter lost in the effluent volume calculated. Nitrogen on the effluent samples was determined by pipetting 20 ml. of the sample into a 300 ml. Kjeldahl flask, adding a few drops of concentrated sulphuric acid, and evaporating nearly to dryness. To prevent bumping, the selenium catalyst in the form of a pellet (approximately 0·1 gm.) was added during the process of evaporation. The digestion was then conducted in the usual way.

2. Sulphur dioxide in the effluent from Tower III was estimated by taking 2 ml. of N/10 iodine solution, diluting with water and adding 10 ml. of 15 per cent. orthophosphoric acid. To the mixture was added 1 ml. of the effluent and the excess iodine titrated against N/100 sodium thiosulphate solution, using starch indicator. The thiosulphate solution was restandardized against the iodine daily, and the results were corrected for the very small blanks obtainable by using the effluent from the untreated silage. The loss of SO_2 through the effluent is indicated in Fig. 2.

The sulphur dioxide in the silage was estimated by taking 25-gm. portions and stirring each rapidly and mechanically for 10 minutes with a corresponding number of 250-ml. portions of distilled water. The products were then filtered, and using 1-ml. quantities of N/10 iodine and 1-ml. portions of the filtrates, and 10-ml. portions of 15 per cent. phosphoric acid, the excess of iodine was titrated against N/100 sodium thiosulphate and the average result calculated. A blank was done on the untreated kale silage but gave a negligible titre.

3. Soluble nitrogen (N_S/N_D) was determined on the dry matters of the kale and kale silages according to the method described by Barnett and Miller [9], and the digestibility (N_P/N_D) of the nitrogen was estimated by Wedemeyer's method.

4. The proportion of hydrolysable carbohydrate was found by the anthrone method as modified by Barnett and Miller [10] for use with silage.

5. Lactic acid was estimated by Barnett's adaptation [11] of the method of Barker and Summerson [12].

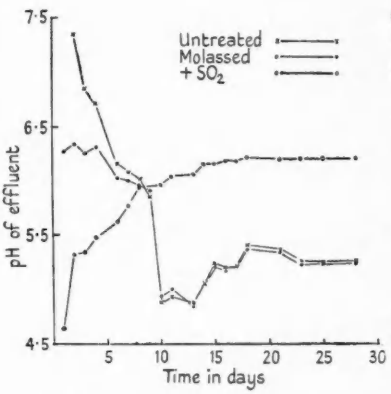

FIG. 1. pH of silage effluents.

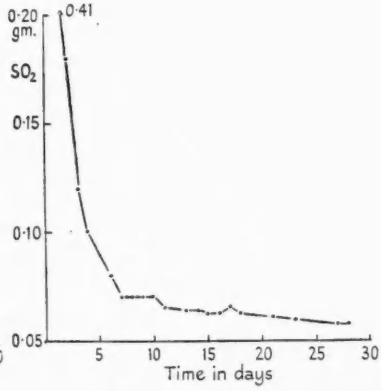

FIG. 2. Elimination of SO_2 in effluent (calculated per 100 ml. of effluent).

Results

The analytical figures for the kale and the three kale silages are given in Table 1. The volumes of effluent from the three towers were, in litres, 11·383, 16·589, and 13·416 respectively; the average pH of the first effluent was 5·70, of the second 5·52, and of the third 5·93. When allowance is made for the 4 litres of water containing the molasses in Tower II, and the flow of effluent is recalculated on the basis of flow per kilogram of ensiled material, it is found that the flow from Tower II is the smallest, the results being 0·127, 0·115, and 0·139 litre.

Of the original dry matter ensiled, 6·24, 7·73, and 7·85 per cent. were lost in the effluents, and the corresponding nitrogen losses, in terms of ensiled nitrogen, were 6·97, 7·58, and 8·09 per cent.

The weights of fresh silage recovered from the three towers were 69·50 kg., 93·45 kg., and 76·05 kg. On comparison of these figures with the amounts of fresh kale ensiled, it is found that the fodder losses were 22·52, 15·58, and 21·23 per cent. When, however, the approximate weights of effluent water and dry matter in the effluent are taken into account, the recovery is fairly good, from an experimental point of view, as will be seen from Table 2.

The foregoing results, taken in conjunction with the weights of dry matter ensiled and recovered in the three silages, make it possible to

TABLE 1. *Analytical Results for Kale and Kale Silage*

Tower	*pH*	*D.M.* %	*N on wet* %	*N on D.M.* %	N_S/N_D	N_P/N_D	*Oil* %	*Fibre* %	*Ash* %	*N.F.E.* %	*Hyd. carb.* %	*Lactic acid* %	SO_4 *(gm.)*
Kale	..	15·63	0·320	2·05	..	78	2·18	14·63	10·54	59·84	..	..	..
Towers													
I	4·10	14·88	0·390	2·17	50	76	2·28	16·46	12·63	55·07	18·00	5·50	..
II	4·16	16·65	0·369	2·25	51	77	2·65	14·98	12·95	55·36	14·80	4·44	..
III	4·65	15·64	0·366	2·45	59	84	2·92	13·35	12·88	55·54	39·25	3·01	31·19

TABLE 3. *Recovery of Nitrogen and Dry Matter*

Tower	*Original D.M. kg.*	*D.M. in effluent and silo*			*Difference kg.*	*Lost in process* %	*Original nitrogen kg.*	*N in effluent and silo*			*Difference kg.*	*Error* %
		Effluent kg.		*Silage kg.*				*Effluent kg.*		*Silage kg.*		
I	14·02	0·875	+	10·34	2·81	20·04	0·287	0·020	+	0·271	+0·004	+1·39
II	17·90	1·384	+	15·56	0·96	5·36	0·356	0·027	+	0·345	+0·016	+4·50
III	15·09	1·184	+	11·89	2·02	13·39	0·309	0·025	+	0·278	−0·006	−1·94

compute the recovery of nitrogen and dry matter (Table 3). The total SO_2 recovered in the effluent of Tower III was 12·14 gm. A summation of the more important losses is given in Table 4.

TABLE 2. *Recovery of Fresh Material (with deduction of the 4 litres of water from Tower II added with the molasses)*

Tower	*Effluent water kg.*	*D.M. in effluent kg.*	*Silage kg.*	*Total recovery kg.*	*Recovery %*
I	11·383	0·875	69·50	81·76	91·15
II	12·589	1·384	93·45	107·42	97·04
III	13·416	1·184	76·05	90·65	93·88

TABLE 4. *Summary of Losses (Gains shown with a positive sign; high ash figure of kale plus molasses due to high ash-content of molasses)*

	Untreated kale %	*Kale plus molasses %*	*Kale plus SO_2 %*
Dry matter . . .	26·25	13·07	21·21
Nitrogen	5·58	3·09	10·03
Oil	22·62	+11·45	+5·47
Fibre	17·01	7·09	28·12
Ash	11·58	+10·27	3·71
Nitrogen-free extract . .	32·26	16·23	27·01
Dig. nitrogen . . .	8·04	4·32	3·32

Discussion

It will be noted first that the losses are extremely small and of nothing like the order mentioned by previous workers. This was partly to be expected in view of the findings of Moore and Wilcox [13], who showed that the normal extravagant losses associated with this process could be substantially reduced if the silage were made in clamps. Secondly, that although the kale was ensiled in frosty weather, which also prevailed during the period of maturing, the fermentation took a normal course as judged by the resultant pH, the effluent flow, and the lactic acid formed. There seems to be little doubt therefore that the normal losses are the results of the violence of fermentation, rather than of the fermentation itself. If this is controlled as in the present instance, climatically so to speak, while the essential fermentation is not interrupted, the losses associated with it are considerably modified. Why the fermentation takes place at such a low temperature is difficult to explain.

Despite the amount of SO_2 throughout the mass in Tower III, the pH is higher than in the other two cases. The protein is more digestible, the fibre-content is lower, and the percentage of hydrolysable carbohydrate is much higher than in the other silages. Moreover, when the three silages were fed to cattle which had not eaten for 8 hours, they attacked the silages in the order 3, 2, 1. The untreated and 'molassed'

silages had the typical 'sauerkraut' smell, but that treated with SO_2 had the odour of fresh kale and retained its bright-green colour. It would seem therefore that there is good reason for testing the partial sterilization of kale on the large scale. On the other hand, the losses involved, although small, are in general higher than those obtained by the molasses process.

The curves in Fig. 1 show that at the outset the untreated material is at a pH somewhere near neutral, but within the first 48 hours the start of fermentation lowers it, and at the end of 8 days it sank to the same level as that of the effluent from the molassed product. At the end of the first 24 hours as a result of quick fermentation, the latter produces an effluent of about pH 5·9, but the ultimate pH of this effluent is no different from that of the untreated kale. The material treated with SO_2 produces at the end of 24 hours an effluent of pH less than 4·6. Thereafter the pH rises to a level of about 6·3 and then remains fairly constant. It is difficult to explain the crossing-point of the curves on the eighth day, but it is a possible point of significance that Virtanen [14] has shown that part of the lactic acid in ordinary non-acidified silage is either lost in the effluent or destroyed about the eighth day of ensilage.

It may be suggested in view of the small losses of dry matter and nitrogen involved (26·25 per cent. dry matter and 9·15 per cent. of nitrogen at the highest) that these would increase as a result of a continuous drip of effluent over a period of months. This is true, but once the fermentation is complete, there is no objection to sealing up the effluent outlet and permitting the soakage to be reabsorbed.

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THE SUDDEN-DEATH DISEASE OF CLOVES AND ITS ECONOMIC AND AGRICULTURAL SIGNIFICANCE

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Control Measures and Statistical Data

THE 'Sudden-death disease' of cloves has been described in detail by Nutman and Sheffield [1]. It results in the death of the affected tree after a variable period during which the tree gradually declines but shows no definite diagnostic symptoms. It is difficult to determine when it first appeared in the Zanzibar Protectorate, as it had been confused with two other diseases. 'Dieback' seems to have been regarded as a different symptom-expression of the same disease until about 10 years ago, and proof that this is not the case is still lacking; and only in 1946 did Briant distinguish between Sudden-death and death due to a rising water-table. It is, however, reasonably certain that the disease has been present for well over half a century.

Many causes, plausible and otherwise, have been suggested, the former falling into two classes: pathological and physiological. As early as 1907 McClellan [2] suggested a fungal origin, but not until 1921 did he succeed in obtaining the appointment of a mycologist. Welsford, who worked on the disease for some years, concluded that it was caused by a specific fungal pathogen, which, however, was not isolated. She also recommended control measures, but we can find no evidence that these were ever given a trial.

During the 1930's the disease became more widespread, and the practice of interplanting plantations to replace losses due to the disease was started. Various speculations by visiting scientists were made on causation and treatment; and a virus was first tentatively suggested by Storey [3] in 1937.

On the advice of Sir Frank Stockdale a pathologist was appointed in 1938. After a year's work Campbell [4], having failed to find a fungal, bacterial, or protozoal parasite, and dismissing the possibility of a virus, on arguments which were not well founded, framed a physiological hypothesis, on the basis of which it was assumed that no further heavy losses would occur; but during the war years the disease continued to spread and the need of further research became recognized. In 1946 the Clove Research Scheme was started with the aid of the Colonial Development and Welfare Funds, and a small team of workers began research in late 1947. It at once became evident to them that the position was alarming. In Zanzibar Island the disease had already involved more than half the total clove-growing area, and about half of the mature trees on the island were dead. In Pemba there were many small but rapidly spreading outbreaks, scattered apparently at random throughout the

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clove-growing districts. Although rigid scientific proof was lacking, Nutman and Sheffield [1] considered that the epidemiological evidence clearly pointed to a pathogen. It was feared that if scientific proof of aetiology were awaited, the disease might become as uncontrollable in Pemba as it seemed to be in Zanzibar.

With the full concurrence of the Department of Agriculture, in January 1949 the staff of the Clove Research Scheme suggested that immediate steps, based on knowledge of similar epidemics in tree crops, should be taken to control the disease in Pemba. It was explained that such measures were in the nature of a calculated gamble, but that they had the support of all pathologists consulted.

Although any attempt at control was eventually abandoned much work was undertaken as a result of the proposal. The main purpose of this paper is to outline the control measures which were suggested, to examine the data acquired, to endeavour to assess the probable future development of the disease, and to discuss the agricultural implications.

Suggested Control Measures

During 1948 Nutman and Sheffield [1] studied the epidemiology of the disease and described the state of affairs at the end of that year; more data have since been obtained and will be discussed later. As soon as the possibility of control was mooted, a survey was made by the Clove Growers' Association and this was checked by Winter. The object was to determine the number, size, and state of activity of the outbreaks. Unfortunately no precise records of their location were made. This survey was admittedly incomplete but it showed there to be not less than 500 separate outbreaks in Pemba Island of an average size of some 30 dead trees. Most of these were recorded as being active.

In October 1948 the Directors of the East African Agriculture and Forestry Research Organization and the Clove Research Scheme submitted joint recommendations based on this survey. By this time, all possible pathogens save a virus, or possibly a fungus, had been virtually eliminated; and it had been suggested that a new species of Saissetia, cultivated by the ant *Oecophylla longinoda*, might be the vector.[1] The control measures advocated by Keen and Nutman were based on the hypothesis of a virus carried by the ant-transported coccid, but were designed so that they would also influence the spread either of a virus transmitted by a different insect or of a fungal pathogen. The control measures proposed were:

1. The felling of all dying and 'suspect' trees with immediate destruction of their insect populations (fire was suggested).
2. The felling of a sanitary cordon. The width of this belt would have been decided for each outbreak separately, from data giving the individual rate of spread. This was the weakest point of the Scheme, since the width of the cordon necessary could not be exactly determined without information as to the period elapsing between infection and death—information which is still lacking.

[1] There was no scientific proof of this but only circumstantial evidence.

3. Grease-banding a further belt of trees to prevent colonization by ants from felled trees.
4. Prohibition of regeneration for two years.

The Keen–Nutman memorandum outlined the necessary organization and, basing its estimates on a liberal interpretation of the data available, and a sanitary cordon of a width largely influenced by experience with the swollen-shoot disease of cacao, concluded that some 60,000 trees would need to be felled in the first instance at a cost of about £150,000, including compensation. Shortly after these proposals were made, an Advisory Mission composed of H. H. Storey, F. C. Bawden, W. J. Hall, and H. Martin was sent by the Colonial Office to study the problem in the field and advise on possible control measures. Meanwhile, Padwick of I.C.I. Ltd. [5] had found BHC dust to be very effective against Oecophylla. The Mission, whilst emphasizing the uncertainty involved in basing control measures on circumstantial evidence instead of scientific proof, agreed that in the circumstances action should not be delayed. They wrote: 'If the future of the clove crop is to be safeguarded, some attempt to arrest Sudden-death is needed. The attempt may fail; but to do nothing would at present most probably lead to the loss of the clove crop in Pemba, as in Zanzibar.' They endorsed, in general, the control measures proposed by Keen and Nutman, but recommended that insecticides should be used instead of fire for vector control; that the whole control programme should be planned on an experimental basis; and they opposed replanting until local scientists considered that any given area was disease-free. It was finally decided to implement the Scheme and a grant of £193,000 was obtained from Colonial Development and Welfare Funds.

The Control Scheme, as planned, was to be highly mechanized and, since so much depended on judgement in the degree of control to be applied to each outbreak, arrangements were made for European supervision of every phase. Transport was to be by 4-wheel-drive vehicles (Landrovers), which experience had already shown to be capable of going almost anywhere in Pemba. These were to be supplemented by crawler tractors for exceptionally difficult terrain. The first operation, dusting, was to be by Long Ashton power-dusting machines, modified to suit forest conditions. After an interval, felling of all suspect trees, plus a sanitary cordon, was to be done by power-driven chain-saws. A final insecticide application to the felled trees was then to be made. Since the equipment was to operate in an isolated island, a fully equipped garage and workshop were also provided. With the willing assistance of the Engineering Staff of the Crown Agents for the Colonies, Dr. Kearns of Long Ashton Research Station, and the various manufacturers concerned, final decisions on equipment were made by April 1949 and orders placed; it was then thought possible to begin operations by January 1950, a date postponed until late in that year.

In September 1949 the survey section, under Winter, began work in the south of the island, charged with the task of finding and mapping in detail every outbreak and investigating land titles. Although no detailed

maps of Pemba have ever been made, the records of an aerial survey made in 1947 were of great help. Within a few months it became evident that the number of outbreaks was far greater than had been thought, that new ones were arising at an unforeseen rate, and that the spread in many areas was rapid. Furthermore, when the original estimates were drawn up, a delay of 2 years had not been expected. New estimates were then made and it was found not only that control would cost much more than expected, but that the number of trees to be felled would be increased by several times. As a result, the Scheme was abandoned and shortly afterwards the detailed survey ceased.

Geographical Distribution of the Disease in Pemba

Fig. 1, based on the results of the 1948 survey, illustrates the distribution of outbreaks. It is known to be incomplete, there being about four times as many outbreaks as are illustrated. There are no cloves (and consequently no outbreaks) in the eastern part of the island because the soil is unsuitable.

A similar map showing the distribution over a small part of South Pemba, based on the accurate 1950 survey, indicates some association between outbreaks—an association which strengthens our view that the disease is pathogenic. The 1950 survey found 434 separate outbreaks in an area almost exactly one-tenth of the area of the whole island, and since approximately half the island is unsuitable for clove-growing, we estimate that between one-fifth and one-sixth of the cloves has been examined. We have no reason to expect a higher or lower concentration of disease in any other part of the clove districts, and on this basis the number of outbreaks in Pemba in 1950 was between 2,170 and 2,604.

Rate of Spread in the Individual Outbreaks

The 1948 survey did not record the precise location of outbreaks and consequently, save in a few instances, death-rates cannot be obtained from a comparison of the 1948 data with the 1950 data. Thirteen of these outbreaks in the south of the island have been positively identified, and others have been recorded at intervals by the Clove Research Scheme. One has been identified by Squire as arising in 1941.

It is evident that the variation is enormous, and when it is remembered that some outbreaks (generally those where the disease is most active) spread fairly uniformly, whilst others are active at portions only of the periphery, it will be recognized that the actual variation is even greater than would appear from Table 1. Consequently, we emphasize the reserve with which any mathematical conclusions must be regarded.

As would be expected, the correlation between the initial size of outbreak (x) and the annual death-rate (y) is positive and highly significant ($r = 0{\cdot}728$), the regression equation being:

$$y = 3{\cdot}49 + 0{\cdot}327x.$$

If the average initial radius and the average annual increase in radius are compared, the correlation coefficient is not significant and the regression curve is horizontal.

These data do not agree with evidence provided by the Survey Section, which rechecked 240 outbreaks after a 6 months' interval. Of these, only 95 were reported as showing any change, and deaths totalled 471,

FIG. 1. Sudden-death outbreaks in Pemba Island based on 1948 survey. There are about four times as many outbreaks as are shown in this map.

an average annual death-rate of almost exactly 4. We believe this to be an under-estimate for the following reasons.

Six months is a very short interval on which to base an average death-rate, since the time at which death occurs is affected to a marked degree by climatic conditions (in Zanzibar by the number of rainy days over a

TABLE 1. *Rate of Increase in Individual Outbreaks*

No. of trees					
1st recording	*2nd recording*	*Increase*	*Interval (months)*	*Annual death-rate (trees)*	*Annual death-rate (%)*
5	7	2	$23\frac{1}{2}$	1·07	21·4
3	9	6	$15\frac{1}{4}$	4·72	157·3
10	29	19	$22\frac{3}{4}$	10·02	100·2
3	10	7	$20\frac{3}{4}$	4·05	135·0
2	4	2	$20\frac{3}{4}$	1·16	58·0
3	18	15	$20\frac{3}{4}$	8·67	289·0
1	4	3	$20\frac{3}{4}$	1·73	173·0
70	111	41	$22\frac{3}{4}$	21·62	30·9
105	189	84	$23\frac{3}{4}$	42·44	40·4
19	23	4	$22\frac{3}{4}$	2·11	11·1
57	59	2	$21\frac{1}{4}$	1·13	2·0
43	104	61	$16\frac{1}{2}$	44·36	103·1
4	12	8	30	3·20	80·0
2	3	1	30	0·40	20·0
10	32	22	30	8·80	88·0
8	21	13	30	5·20	55·0
7	16	9	30	3·60	51·4
4	24	20	18	13·33	333·3
4	13	9	18	6·00	150·0
6	11	5	18	3·33	55·5
1	6	5	18	3·33	333·0
5	11	6	16	4·50	90·0
1	63	62	108	6·89	689·0

given period). Deaths are therefore not regular and show marked seasonal variations, being fewer in wet weather and much more frequent in the dry season. Moreover, if the first recording was made during or after a drought period, which accelerates death-rate, and the second during or after wet, cool weather, the recorded death-rate would be low. Some trees which, under average conditions, would have died between the recordings would die earlier because of drought, and similarly others would die after the second recording instead of just before it. This is precisely what happened in this case, the first recordings being taken after a very severe drought and the second after a heavy rainy season and cool weather.

Confirmation of this is given in Table 2, which compares the death-rates of 10 outbreaks over a considerable period with death-rates during the same 6 months' interval. It will be seen that the average annual death-rate of the 10 outbreaks concerned is 9·45, whereas over the last 6 months of the same period it is 2·0, a reduction of over $\frac{3}{4}$. If this relation held true for all recorded outbreaks, the annual average death-rate would be about 16.

On this same basis the deductions made from the data in Table 1 are open to criticism, as are any data which do not take in an equal number of seasons.

TABLE 2. *Relation between Death-rates over Extended Period and Death-rates in the six months of spread in South Pemba*

Size of outbreak 1st recording (trees)	*Period (months)*	*Annual rate over whole period*	*Rate per annum over last 6 months*
5	$23\frac{1}{2}$	1·07	0
10	$23\frac{3}{4}$	10·02	2
3	$20\frac{3}{4}$	4·05	0
2	$20\frac{3}{4}$	1·16	0
3	$20\frac{3}{4}$	8·67	0
1	$20\frac{3}{4}$	1·73	0
70	$22\frac{3}{4}$	21·62	12
105	$23\frac{3}{4}$	42·44	2
19	$22\frac{3}{4}$	2·11	2
57	$21\frac{1}{4}$	1·13	2
27·5	..	9·45	2

Frequency-distribution of Size of Outbreak

The 1948 survey recorded 473 outbreaks over the whole island and the 1950 survey mapped 434 in South Pemba. Fig. 2 illustrates the frequency-distribution of both, expressed as percentage frequency. Both are very close to the exponential form and analysis shows there to

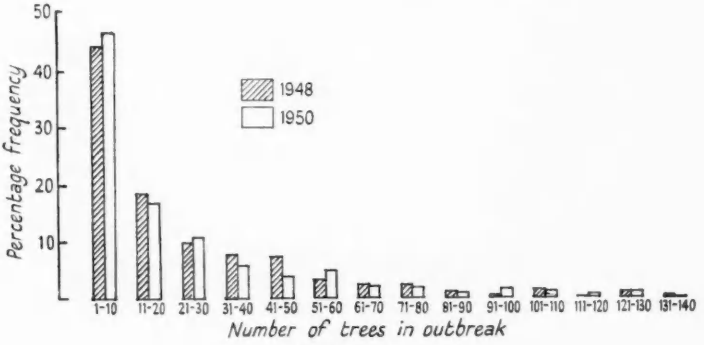

FIG. 2. Frequency-distribution of outbreak-size in Pemba.

be no significant difference between them. The equation for the 1950 data is

$$\log F = 1{\cdot}3971 - 0{\cdot}0312x$$

where F is the percentage frequency and x is the mean number of trees in the outbreak-size class. Fig. 3 shows, with closer groupings, the distribution of the smaller outbreaks. Even here the smallest group is the most frequent, and this is true when the class-interval is reduced to a

single tree. As the situation is not static, the size of the outbreaks increasing with time, this can only mean that new small outbreaks are continually arising, for only in this manner can the frequency-distribution remain constant. As a corollary to this, the average outbreak-size will be constant at about 25 trees.

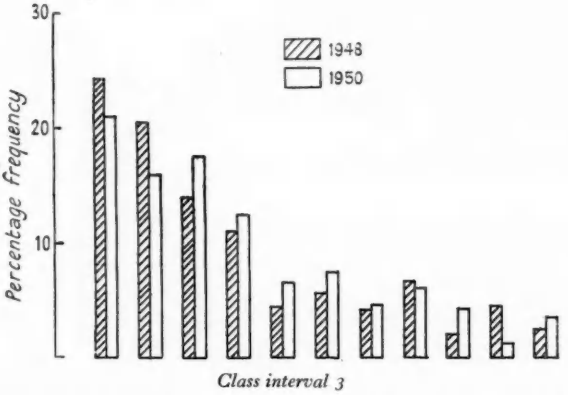

FIG. 3. Frequency-distribution of all outbreaks of less than 33 trees.

Increase in Total Number of Outbreaks

Since the 1948 survey was incomplete, no direct evidence on the rate of increase is obtainable, but observations show that new outbreaks do arise; and there are three lines of evidence which enable an approximation to the rate to be obtained.

1. Recorded outbreaks in South Pemba are as follows:

District	*Total number of outbreaks*	*Number thought to have arisen since the 1948 survey*
Fufuni . .	46	11
Kengeja . .	22	6
Mkoani . .	90	18
Jambagone . .	111	36
	269	71

An element of doubt exists in 14 out of the 71 cases. Omitting these from the calculation, the rate of increase in number is 14 per cent. per annum.

2. Between 1938 and 1940, I. G. C. Squire, an experienced officer of the Zanzibar Department of Agriculture, made a detailed survey of 43 clove plantations in the Mkoani district. He recorded that Sudden-death was present in or near two of these. His survey, so far as can be calculated, covered about one-fifth of the tree-sites in the district. On this basis a

rate of increase of more than 14 per cent. is required in order to produce the 104 outbreaks recorded in this district.

3. The data on frequency distribution can also be utilized. Of the outbreaks in South Pemba, 7·4 per cent. are single trees, and there is every reason to assume that this figure will remain approximately constant. On the average it takes something less than 6 months for a single-tree outbreak to become a 2-tree outbreak, and in order to restore the constancy of the frequency distribution, not less than 14 per cent. of new outbreaks must arise each year.

We therefore think that 14 per cent. is a conservative figure for the annual rate of increase in number of outbreaks, but must point out that, in all probability, the number will vary greatly from year to year.

The Probable Future Development of the Disease

It is clearly of the greatest practical importance to be able to forecast, however approximately, the rate at which Sudden-death can be expected to spread: for this estimate can be used to determine the rate at which alternative development should be encouraged. We realize the difficulties inherent in such a forecast and point out that our conclusions must be regarded as tentative. Not only are the factors which form the basis of our calculations approximations, but other factors that may operate in the future are unknown. This point will be referred to later. Additional difficulties are introduced because no agricultural statistics are available: even the total acreage under cloves or the total number of clove trees in Pemba is unknown, although Tidbury [6] concludes that there are about $2\frac{1}{2} \times 10^6$ trees on Pemba Island. To forecast the future we must know:

(*a*) The total population. We have taken this to be 2,750,000 trees in 1930, giving, according to our calculations, rather more than $2\frac{1}{2}$ million in 1950.

(*b*) The number of outbreaks. We have assumed 2,100 in 1950, a conservative estimate.

(*c*) The annual increase in this number, which we believe to be not less than 14 per cent. We have calculated on this basis; and also on 10 per cent., a figure which may be too low.

(*d*) The death-rate of the average outbreak, which on the evidence will remain constant. We have calculated on 11 deaths per annum, which is the figure given by the regression equation. We have also calculated death-rates at a figure of 8 per annum, this being twice the rate recorded for South Pemba, as this rate is known to be too low.

Approximations to all these have now been obtained; but there are several contributory factors which must be borne in mind when studying the results arising from the data.

The figure for the rate at which new outbreaks arise, even if accurate for the present stage of the epidemic, will certainly not remain constant,

and we would expect it to increase in the later stages. The rate of spread of the individual outbreak will similarly alter in the future and two of the ways in which it may do so should be recognized. First, adjacent outbreaks may coalesce, and in fact this has been observed. When this happens the length of the periphery of the two will be reduced, and if the radial spread remains the same, the death-rate of the two will be reduced somewhat. On the other hand, as outbreaks become more numerous, the diffuse epidemic phase may set in. If this happens, death-rates are likely to increase considerably and may reach the intensity recorded in Zanzibar, i.e. more than 20 per cent. per annum over a wide area [1]. It is, of course, impossible to say which of these two tendencies will prevail.

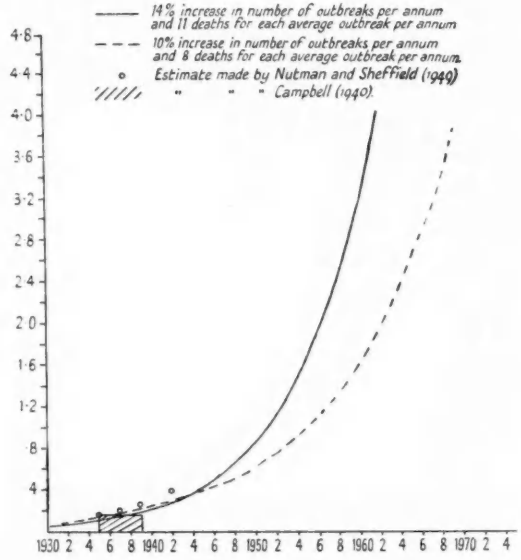
14% increase in number of outbreaks per annum and 11 deaths for each average outbreak per annum
10% increase in number of outbreaks per annum and 8 deaths for each average outbreak per annum
Estimate made by Nutman and Sheffield (1949)
" " Campbell (1940)
4·8
4·4
4·0
3·6
3·2
2·8
2·4
2·0
1·6
1·2
8
4
1930 2 4 6 8 1940 2 4 6 8 1950 2 4 6 8 1960 2 4 6 8 1970 2 4

FIG. 4. Percentage death-rates in Pemba based on a stand of 2·75 million trees in 1930 and 2,100 outbreaks of disease in 1950.

Other factors at present quite unrecognized may affect the future. It is well known that some outbreaks, after having spread for a time, become quiescent, and only speculative explanations for this can be advanced; it is possible that whatever the cause, it may become more effective in the future, although we have no reason to suppose so. In fact, theory and the past development of the disease in Zanzibar make us incline to the view that the reverse is the more probable.

Fig. 4 shows the death-rate in Pemba expressed as a percentage, based on the factors already discussed. Two curves have been drawn; the first is that given by a precise application, and the second is based on the most optimistic interpretation of the data which we can justify. These curves

have also been extended into the past and we have shown the death-rates as estimated by Nutman and Sheffield [1], using entirely different criteria; also that obtained by Campbell [4] as the result of an admittedly incomplete survey.

Fig. 5 shows, on the same basis, the accumulative death-rates expressed as the percentage loss of stand.

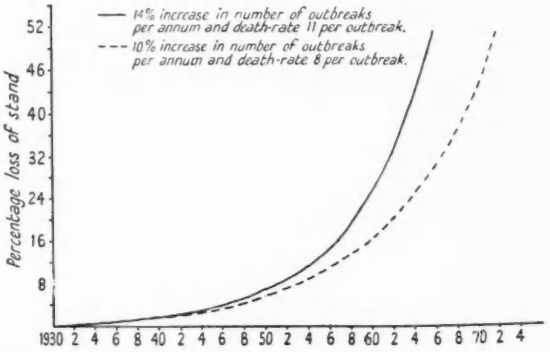
14% increase in number of outbreaks per annum and death-rate 11 per outbreak.
10% increase in number of outbreaks per annum and death-rate 8 per outbreak.
Percentage loss of stand
52
46
40
32
24
16
8
1930 2 4 6 8 40 2 4 6 8 50 2 4 6 8 60 2 4 6 8 70 2 4

FIG. 5. Cumulative death-rates in Pemba expressed as percentage loss. Based on 2¾ million trees in 1930 and 2,100 outbreaks in 1950.

Forecast of the Economic Implications of the Disease

The clove has long been the economic mainstay of the Zanzibar Protectorate, and although recent high prices have brought the coconut much more to the fore than formerly, it is nevertheless quite inconceivable that the latter crop could by itself maintain the living standards of the population at anything like their present level. Added to this, few products have such a tendency to suffer from price collapses in times of plenty as some of the low-grade vegetable oils, as witness copra itself, which fell from £90 per ton at the close of the 1914–18 war to £5 per ton in 1934.

Present practices of bulk-buying, guaranteed prices, and long-term contracts are unlikely to permit of such disastrous fluctuations, but there is no reason to assume that vegetable oils will remain at their present high prices, and little to assume that the almost inevitable reduction in prices will be balanced, or even cushioned, by any commensurate decrease in the cost of living. By contrast, the price of cloves has not, for the past 50 years, fallen below just over 30*s*. per 100 lb., a figure, taking into consideration the general increase in the value of primary products, not unreasonably comparable with the Clove Growers' Association's present 'floor' price of 90*s*.

The following figures (Table 3) emphasize the importance of the clove trade to Zanzibar and the immense difficulty which will be encountered in filling gaps which any collapse of the industry will leave.

TABLE 3. *Values of Exports of Clove and Coconut Products exported from Zanzibar*

Year	*Clove products*	*Coconut products*	*All other domestic products*	*Clove products exported as % of total exports*
Average	£	£	£	
1934–8	519,106	134,427	11,687	78·06
1945	686,538	249,336	67,327	68·57
1946	1,243,106	285,245	170,832	73·15
1947	627,467	355,209	88,130	58·60
1948	1,071,100	278,763	78,512	74·99
1949	921,051	1,105,101	73,531	43·87

Similarly the Protectorate is to a substantial extent dependent on clove and stem duties (Table 4).

TABLE 4. *Revenue from Clove and Stem Duties*

Year	*Total Protectorate revenue*	*Clove and stem duties*	*Percentage of whole*
Average	£	£	
1934–8	468,956	95,225	20·31
1945	628,866	105,956	16·85
1946	795,063	195,314	24·57
1947	746,332	98,329	13·17
1948	809,451	184,922	22·85
1949	1,118,508	151,508	13·55

To the significance of the above figures must be added the purchasing power, reflected in import duties and other revenue, which is provided by exports of clove products of an average value of little under £1,000,000.

The situations in Pemba and in Zanzibar are not comparable. Areas suitable for clove cultivation are more extensive in Pemba than in Zanzibar, and consequently there are more trees in the former island, which is estimated to contain some 2½ million compared with a stand of not more than 750,000 in Zanzibar. Over the past 10 seasons Pemba has produced an average of 7,863 tons of buds, compared with Zanzibar's 2,204 tons. For coconuts the position is reversed, as about 75 per cent. of the Protectorate's total production of 14,000 tons comes from Zanzibar.

Thus Zanzibar Island has already to some extent adjusted its economy to the conditions produced by the onslaught of Sudden-death, and this adjustment is being continued by the increased planting of coconuts and, though still on a small scale, by the encouragement of cacao and other alternative crops. Moreover, Zanzibar has a tourist and entrepôt trade

to assist her economy, but Pemba has not the agriculturally unproductive population contained in Zanzibar town.

The immediate problems are whether the clove industry can be preserved in one or both islands, and whether any such efforts at preservation are to be conducted on a planned basis or left to haphazard regeneration and the workings of a not necessarily beneficent Providence. It is a natural corollary that, if preservation is impossible, some crop or crops, and preferably a tree crop, must be found to fill the gap. According to the evidence already presented, it will be between 10 and 20 years before the problem in Pemba becomes so acute that the economic position of the island will be grave.

Assuming the virus hypothesis to be correct, there are two sound and realistic approaches to the problem, both based on the assumption that physical control of the disease in the present stand of trees is impossible. The first is to abandon the clove industry and to replace it by as good an economic equivalent as possible; the second is to endeavour to eliminate the disease by complete destruction of all plants in which it could exist, followed by replanting after a quarantine period. This, with suitable modifications, would serve equally well if the causal agent was eventually found to be fungal. Either of these solutions could be applied to both or either of the islands, though the second would not be politically and economically practicable in Pemba until the destruction of trees by the disease is far more advanced than at present. We have purposely omitted the even more attractive prospect of finding highly resistant or immune stock, since this denouement is not likely to be realized.

The idea of disease elimination and subsequent ordered rehabilitation is an attractive one. It was first suggested by the Advisory Mission, which considered that, in Zanzibar, 'the only thing possible seems to be to let the disease run its course, planting the devastated areas either with other crops or replanting with cloves after all standing trees over a large area have been killed or cleared'. The present rather untidy monocropping could be replaced by a well-balanced system, the clove being allowed to fill a prescribed and limited place in such a picture. The climate of the Protectorate is, on the whole, a kindly one, certainly unique in East Africa; and soil conditions, though variable, are sufficiently suitable for the majority of tropical tree crops to permit of considerable diversity. The rapidly expanding markets of East Africa are on the doorstep, and internal and external communications are excellent.

Cacao, citrus, kapok, and all tropical fruits flourish; and *liberica* coffee, though no rival to the *arabica* of the mainland highlands, has its own market. As ground crops, both derris and pineapple offer remunerative possibilities, whilst the supply of chillies and peppers seems to lag behind world demands. Nor need the possibilities of essential oils, such as lime and ylang-ylang, be neglected; and the candle-nut, source of lumbang oil, also flourishes.

There are already areas in Zanzibar, up to perhaps a square mile, where the remaining cloves are so few and of such indifferent size and vigour that clearing could be done, and adequate compensation paid, at small cost. When all possible alternative hosts had also been destroyed,

the land would be put down to ground crops, partly as alternative sources of revenue, partly to assist in the elimination of alternative hosts. This quarantine period need not be long, two years should be adequate; there would also be ample time for planning the layout of the area.

We consider that, in order to give the greatest possible chance of success, the area should be under unified control, and run on 'plantation lines', perhaps under some such form of organization as the Sudan Plantations Syndicate; but this would seem to be politically impossible under Zanzibar conditions.

If this be so, could a scheme based on co-ordinating the activities of the scores of smallholders involved be successful? We think it should be tried, although it must be admitted that the chances of success are reduced because of the abandonment of unified control, authoritative supervision, and modern methods. It has been said that such a scheme of rehabilitation could not, under Zanzibar conditions, be carried out except on a voluntary basis. If this opinion be correct, it is regarded by the authors as an outlook of despair, and it will inevitably result in a palliative incapable either of meeting the economic requirements of the Protectorate or of maintaining a disease-free clove industry. A large measure of agreement and support from plantation owners and the public generally is essential, but legal sanctions are indispensable for dealing with the backslider and non-co-operator.

What form might such a scheme take? We envisage that after clearing and an interval during which ground crops are grown, replanting with tree crops would be permitted. Advice would be given on the layout of each plantation, but the only hard-and-fast restrictions would be on the planting of cloves. These would be in small, compact blocks, separated either by belts of ground crops or of other tree crops, which should mutually provide a degree of pest and disease protection. Probably orange, grapefruit, cacao, cloves, limes for lime oil, coffee, kapok, and a few more tropical fruit trees would provide the best mixture.

It is not to be expected that even the best-intentioned owners would, or could, do all that is required without assistance, and this might be provided by something similar to the Trinidad Cocoa Subsidy Scheme. This would be augmented by the distribution of free seedlings and the marking out of planting sites. The provision of these facilities at public expense would go far towards justifying the measure of compulsion which must form part of any realistic solution of the problem. Facilities in the Clove Growers' Association already exist for the marketing of produce, and the same organization might well undertake necessary processing, such as distillation of essential oils.

What is the alternative to some such scheme of rehabilitation? Either regeneration in infected areas could be forbidden, in which case the disease might be expected, alternative hosts apart, to die out with the last clove tree; or, as in fact would happen, replanting could continue unchecked, even if not encouraged, throughout both islands.

In the first place it would be many years before a locality could be pronounced 'clean', as Sudden-death by no means always makes a clean sweep, and our present knowledge would not allow us to pronounce any

tree free from infection because it had failed to die at the same time as its fellows. In the second case, regeneration would inevitably result in perpetuating the disease, and if, as appears probable, younger age-groups are now being attacked and the over-all incidence of the disease is increasing, less and less probable ultimate reward would accrue to the producers.

We realize that many imponderables are involved; that the scientific issues are by no means proven; that political difficulties abound. We feel, however, that there is more than a case for taking bold and definite action, at least in a pilot scheme big enough to show the way, to bring difficulties to the fore, and to provide the information necessary for more comprehensive treatment in the future.

Summary

1. As the result of epidemiological evidence on the rate of spread of the Sudden-death disease of cloves in Pemba, the situation was thought sufficiently serious to justify an attempt to control the disease in advance of scientific proof of its aetiology. Although this attempt was eventually abandoned, many data were collected in preparation for it. This article reviews the history of the abortive control scheme, and discusses the data acquired.

2. From the results of a partial survey made in 1948 and another in 1949–50, there is an estimated total of over 2,000 separate outbreaks of disease in Pemba. These vary in size but average 25 dead trees. New outbreaks are constantly arising and the present annual rate of increase in number of outbreaks would seem to be about 14 per cent. Outbreaks increase in size at a highly variable rate but, on the average, the radial rate of spread is approximately constant. An attempt has been made to forecast the probable future development of the disease.

3. The effects of the disease on the economy of the Protectorate is discussed, and on the assumption that direct control is a practical impossibility suggestions are made for rehabilitation in Zanzibar Island, where up to the present the disease has caused much greater destruction than in Pemba. These are based on elimination of residual sources of disease in already devastated areas, followed by planned replanting with cloves and with other crops in order to achieve diversity.

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THE MECHANICAL APPLICATION OF FERTILIZERS IN FIELD EXPERIMENTS

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In agricultural field experiments the treatments applied to soil or crops should be specified exactly. In experiments where fertilizer is applied to all plots and other factors are tested (e.g. different varieties or cultivations) each plot should have the same quantity of fertilizer evenly distributed. In experiments testing different rates and forms of fertilizers or different methods of application, then crop variety, plant density and cultivations should be uniform over the experimental area whilst the quantity of fertilizer for each plot and the way it is applied must be known. In experiments where fertilizer is broadcast by hand on small plots, even and accurate spreading depends only on the skill of the experimenter. With large plots it is difficult to broadcast uniformly by hand, and machines may have to be used. Machines must also be used when fertilizer dressings are localized by drilling with, or in some position near to, the seed.

Although special machines have been designed to deliver precise quantities of fertilizer, these are not manufactured in England and are costly to construct. Local workers must rely mainly on using ordinary distributors that may be available. The tests on mechanisms described here are intended to guide workers who may have to use commercial fertilizer distributors in field experiments. The full nature and extent of variations in delivery rates characteristic of particular machines will not be disclosed by an occasional field calibration. With a given setting, variations in the quantities of fertilizer delivered by a drill are caused by the 'condition' of the fertilizer and the characteristics of the distributor. Both causes of variation have been investigated by Mehring and Cumings [1]. Fertilizer 'condition' implies a description of particle size and shape and the behaviour of the material in contact with a humid atmosphere. Data are presented here to demonstrate the effect of storage on the moisture-contents of powdered and granular fertilizers and on their behaviour in drills.

The main types of fertilizer distributors used in Britain have been described [2]. For experimental purposes mechanisms should be used which have a positive action and deliver a definite amount of fertilizer while the drill travels a given distance. As all distributors deliver fertilizer by volume and not by weight, changes in bulk density are inevitably reflected in changes in the weight of fertilizer delivered. There are several mechanisms fitted to drills which should deliver a definite volume for a certain amount of movement in the parts which displace fertilizer. These are star-wheels, plates fitted with scrapers or flickers, and vertical wheels or fluted rollers. Units embodying each of these principles were built and used in the laboratory tests described here.

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Two special machines have been used for distributing fertilizer in experiments. Top-delivery machines are usually based on a design used extensively in American experiments on fertilizer placement. Similar drills have been built in England and the factors affecting the accuracy of the fertilizer delivery units have been described [3*a*, 3*b*]. In the tests described here top-delivery units were included for comparison with the other mechanisms that are widely used in ordinary fertilizer distributors. One top-delivery distributor designed to broadcast fertilizer has been manufactured. A long hopper was fitted with a movable bottom which rose steadily as the drill moved forward; fertilizer was forced in contact with a revolving paddle-wheel at the top of the hopper and was broadcast behind the drill. A machine of similar pattern has been built and tested by the National Institute of Agricultural Engineering [4]. Such machines reduce the effect of condition of the fertilizer on rate of application. They are excellent for broadcasting fertilizer uniformly over large plots provided that precautions are taken to eliminate the effect of consolidation of fertilizer in the hopper by running the drill over non-experimental land and rejecting the initial output.

Recently workers in the United States have used 'end-delivery' machines in experiments on fertilizer placement. These machines were first described by Fairbank and Minges [5]; recently Cumings, Hulburt, and Eldredge [6] have described an adaptation of the mechanism to deal with radio-active fertilizers. The amount of fertilizer needed for a length of row is spread evenly on the upper section of an endless belt. The belt is moved forward slowly by a drive from the land-wheels and fertilizer is delivered continuously to a coulter working in the soil. The drive to the belt is arranged so that the load of fertilizer is discharged exactly within a certain distance. Even delivery from such machines depends only on positive drive from a land-wheel and on uniform spreading of the fertilizer along the belt. Drills fitted with this end-delivery mechanism are indispensable in experiments where a number of different fertilizers or mixtures of fertilizers having varying bulk densities are to be distributed, perhaps at several rates.

Descriptions of the Mechanisms Tested

Top-delivery cylinder.—This mechanism has been described previously [7 *a* and *b*, 8]. Units of a fertilizer-placement drill built for row-crops were used in the tests described here.

Plate-and-scraper.—A circular plate of 6-in. diameter was fitted in the bottom of a hopper (Fig. 1). An opening in the front of the hopper was fitted with an adjustable gate to regulate the amount of fertilizer delivered. A scraper on the plate diverted the flow of fertilizer to a delivery tube. Broadcast distributors employing this mechanism usually have a dished plate which revolves slowly; flickers rotating on a high-speed shaft scrape the plate clear and broadcast fertilizer behind the drill. The half of the plate within the hopper acts as an agitator and ensures uniform delivery. The theoretical volume of fertilizer delivered for one revolution of the plate is the volume of an annular ring having

a cross-section equal to the area of the gate-opening. The plate is covered with fertilizer from the bulk in the hopper above by gravity, and positive delivery depends on the absence of 'slip' between the fertilizer and the plate surface within the hopper. Delivery rates are directly proportional to plate-speed (unless there is slip between plate and fertilizer), but 'condition' of the fertilizer affects its bulk density and dry material may move more easily than wet through the gate-opening.

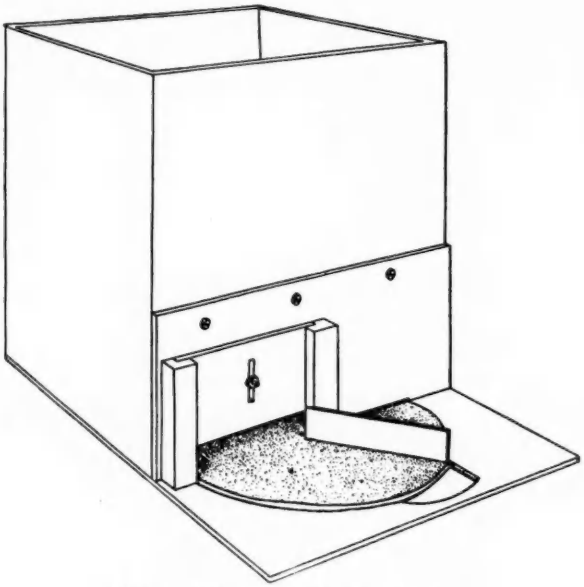


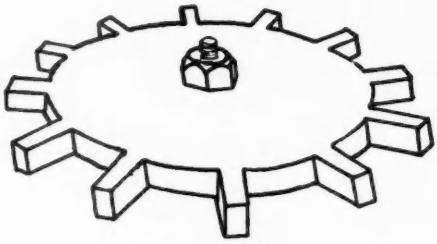
FIG. 1. Plate-and-scraper mechanism.

Star-wheel.—Star-wheel mechanisms consist of a wheel having widely spaced teeth on the circumference. Two types are commonly used. Thick wheels have widely spaced, deep teeth which may be straight or curved. Thin wheels generally have more closely spaced triangular teeth with a smaller area between the teeth. Fertilizer is removed from the hopper in the spaces between the teeth. Usually the machines are designed so that a further quantity of fertilizer may be carried out of the hopper on the teeth and on part of the upper surface of the wheel, an adjustable gate is fitted and a scraper to divert the flow of fertilizer. The thick type of wheel removes fertilizer from the hopper mainly in the spaces between the teeth. Thin wheels may be regarded as modified plates; the teeth act as agitators, a little fertilizer is delivered by the spaces between the teeth but the bulk is delivered by the upper surface of the wheel.

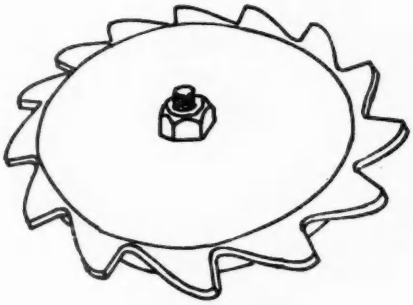
Examples of both types of star-wheel (Fig. 2) were tested. A thick wheel (A) with straight teeth was made at the National Institute of

Agricultural Engineering. It had 6 in. diameter and was $\frac{3}{8}$ in. thick; there were 12 teeth, $\frac{1}{4}$ in. wide, and $\frac{3}{4}$ in. long. A thin wheel (B) of standard pattern manufactured commercially was also tested; its diameter was 6 in. and thickness $\frac{1}{8}$ in.; and there were 14 triangular teeth each $\frac{1}{2}$ in. long.

Theoretically the volume of fertilizer delivered by one revolution of a star-wheel is the total volume enclosed between the teeth. When a



Star-wheel 'A'



Star-wheel 'B'

FIG. 2.

gate is fitted the volume of an annular ring with a cross-section equal to the area of the gate-opening must be added. The space between the teeth is filled by gravity assisted by the agitating action of the wheel and teeth. The delivery rate may be varied by altering the speed of the wheel or adjusting the gate-opening. Irregularities in delivery may arise if the spaces between the teeth are not filled completely. If 'slip' occurs between the wheel surface and the fertilizer, when the gate is open delivery will not be directly proportional to speed.

Vertical wheel.—Vertical-wheel mechanisms consist essentially of a toothed wheel revolving on a horizontal axle. Fertilizer falls by gravity into the spaces between the teeth and, as the wheel revolves, is discharged into a delivery tube. Drills with this type of feed may have an extra opening above the wheel fitted with an adjustable gate which allows more fertilizer to be delivered than is contained between the teeth.

Such an opening may allow granular fertilizer to flow at uncontrolled rates but is necessary when badly conditioned powdered fertilizers are used. Generally a shaft fitted with paddles rotates in the hopper to assist gravity-flow to the wheel and prevent 'bridging' of fertilizer.

The mechanism is fitted to drills designed to place fertilizer in rows; broadcast distributors may be fitted with a fluted roller which behaves in the same way as a toothed wheel. Other gravity-fed distributors of

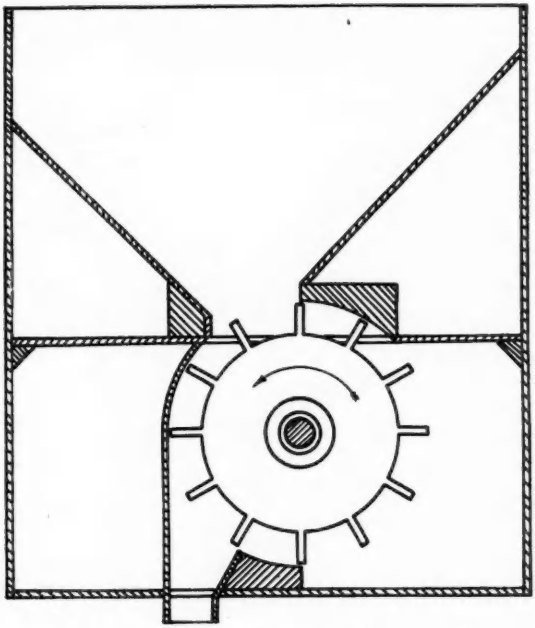


FIG. 3. Vertical wheel.

similar performance used to broadcast fertilizer have three perforated plates in the bottom of the hopper. On some drills the top and bottom plates reciprocate, on others only the middle plate moves. Fertilizer fills the holes in the upper plate, the plate then moves sideways and the fertilizer falls to the ground. Delivery of fertilizer from vertical wheels depends on the volume enclosed between the teeth, on the speed of the wheel, and on any gate-opening that may be used. The delivery rate of reciprocating-plate machines depends on the volume of the holes in the upper plate and the speed at which the plates move.

A hopper was fitted with a wheel of $6\frac{1}{2}$ in. over-all diameter and $\frac{3}{4}$ in. thickness. There were 12 thin teeth, each 1 in. long. The wheel (Fig. 3) revolved in the bottom of the hopper and was arranged so that 2 spaces between teeth were exposed at one time. The sides of the hopper sloped down to the wheel; no agitator was fitted.

Fertilizers tested.—Commercially-prepared batches of both granular and powdered National Compound Fertilizer No. 1 (7% N, 7% P_2O_5, 10·5% K_2O) were used in the tests. A single batch of each fertilizer was used and fresh samples were taken from the bulk for individual tests to avoid progressive deterioration in physical state by grinding in the machines. All fertilizers were passed through a $\frac{1}{4}$-in. screen.

Samples with different moisture-contents were used in tests demonstrating the effect on delivery rate of using moist fertilizer. Before all other tests the fertilizers were stored for several weeks in a warm, dry basement-room (temperature 55–60° F., relative humidity 45–50 per cent.). The moisture-contents (determined by drying at 100° C. for 24 hours) and angles of repose were:

	Per cent. of water	*Angle of repose (degrees)*
Powdered fertilizer . .	3·2	39
Granular fertilizer . .	2·3	36

Effect of moisture in fertilizers on delivery rates.—Tests were made on the effect of the moisture-content of fertilizers on delivery rates, samples of granular and powdered materials stored in a shed during the autumn being used. The fertilizers, stored in jute sacks, were protected from rain and were raised above the floor, but they were not protected from changes in atmospheric temperature and humidity. When taken from store their characteristics were:

	Per cent. of water	*Angle of repose (degrees)*
Powdered fertilizer . .	10·6	52
Granular fertilizer . .	2·9	36

Granular fertilizer stored in damp air absorbed only a little extra moisture, presumably on the surface of the granules; there was a large increase in the moisture contained by powdered fertilizer stored in the same way. Samples of these fertilizers were used in tests on the top-delivery cylinders and were compared with similar tests on the dry fertilizers; the results are given in Fig. 4. A similar test with damp materials was made on the plate-and-scraper model machine; afterwards batches of damp fertilizers were exposed to dry air and the tests were repeated at intervals as the materials dried. The results of tests with the plate-and-scraper are given in Fig. 5 (the percentages of water held by the fertilizers used are stated on the delivery curves). Similar tests on the model machine incorporating the thick star-wheel (A) were made using damp and dry fertilizers (Fig. 5).

There were only small differences in delivery rates between 'moist' (2·9 per cent. water) and 'dry' (2·3 per cent. water) granular fertilizers when tested in the plate-and-scraper or star-wheel model machines, but delivery of moist granular fertilizer by top-delivery cylinders was more irregular than delivery of drier material.

The moisture-content of powdered fertilizer had a large effect on delivery from all the machines. With damp powder there was a serious delay before any fertilizer was delivered from the top-delivery cylinder, and the piston rose one-fifth of its total travel before delivery was at all

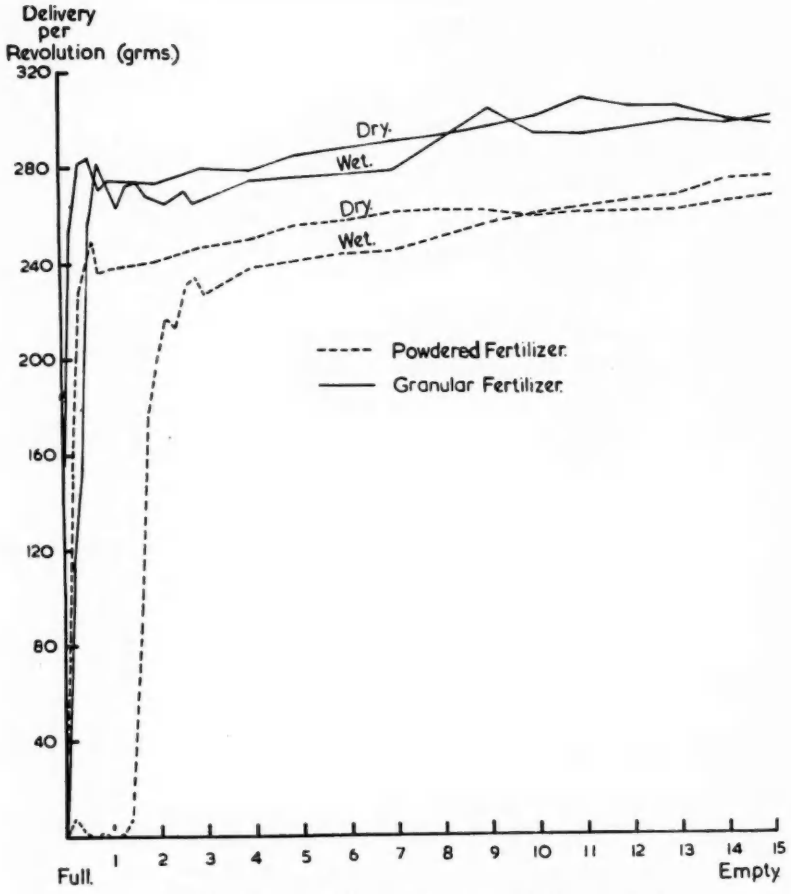


FIG. 4. Variations in delivery rate of a top-delivery cylinder.

constant (Fig. 4). Gate-openings of 4 mm. or less had hardly any effect on delivery of moist powder by the thick star-wheel (A), since a compacted mass of fertilizer formed behind the gate on the surface of the wheel (Fig. 5).

Variations in delivery rate.—Where a number of plots are to be dressed consecutively or larger areas are dressed uniformly, a large quantity of

fertilizer may be used, and it is important that the rate of application should remain reasonably constant throughout the work.

Each model machine was filled with fertilizer and the mechanism was turned at a constant (slow) speed. The output given by a number of revolutions was weighed. The test was repeated until no more fertilizer was delivered. The amount remaining in the hopper was weighed.

In field tests, after initial irregularities, deliveries from the top-delivery machine rose until the cylinders were empty (Fig. 4). With

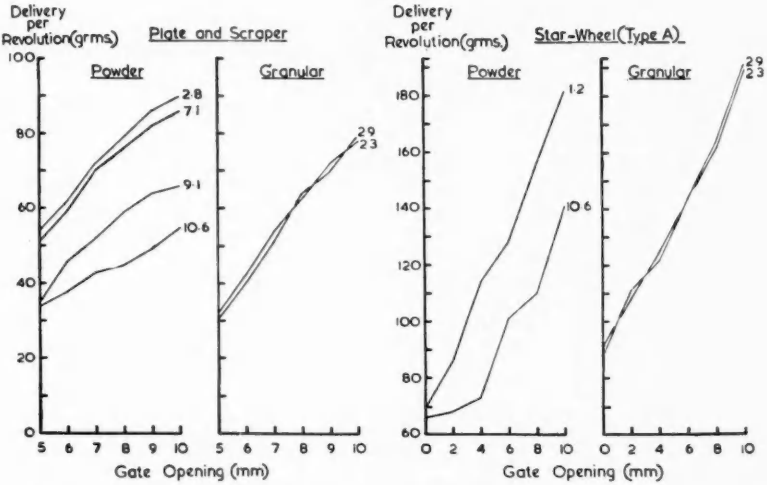


FIG. 5. Influence of fertilizer condition on delivery rate. The percentages of water in the fertilizers used are stated on each delivery curve.

dry granular fertilizer there was a broad maximum in the delivery curve when a quarter of the fertilizer remained in the cylinder.

The plate-and-scraper and star-wheel (type A) model machines gave fairly steady delivery over the greater part of the hopper capacity (Figs. 6, 7). With a narrow gate-opening (0·25 in.) delivery from the plate was very irregular (due to small lumps of fertilizer jamming together across the gate). The thin star-wheel (B) was less satisfactory (Fig. 7).

Delivery of both fertilizers from the vertical-wheel model machine was very erratic (Fig. 6). With granular fertilizer, delivery stopped abruptly when the hopper was two-thirds empty; the remainder of the fertilizer in the hopper sloped down from the sides leaving a clear space above the wheel. Delivery of powder ceased when one-tenth of the fertilizer in the hopper had been delivered; a cylindrical cavity was formed having vertical walls and extending from the wheel to the surface of the fertilizer.

Effect of speed on delivery rate.—The only way of varying the rate of fertilizer from top-delivery cylinders is to vary the speed of the drive.

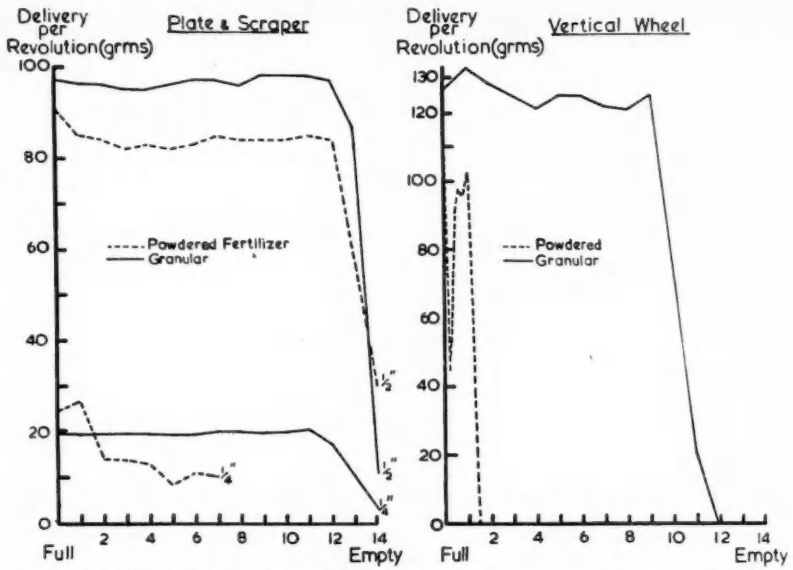


FIG. 6. Variations in fertilizer delivery rate. Gate-openings are stated on each delivery curve.

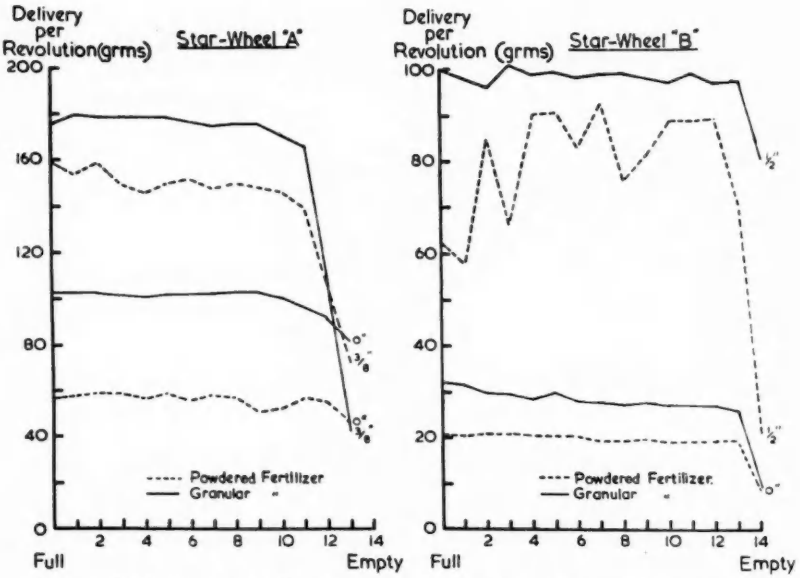


FIG. 7. Variations in fertilizer delivery rate. Gate-openings are stated on each delivery curve.

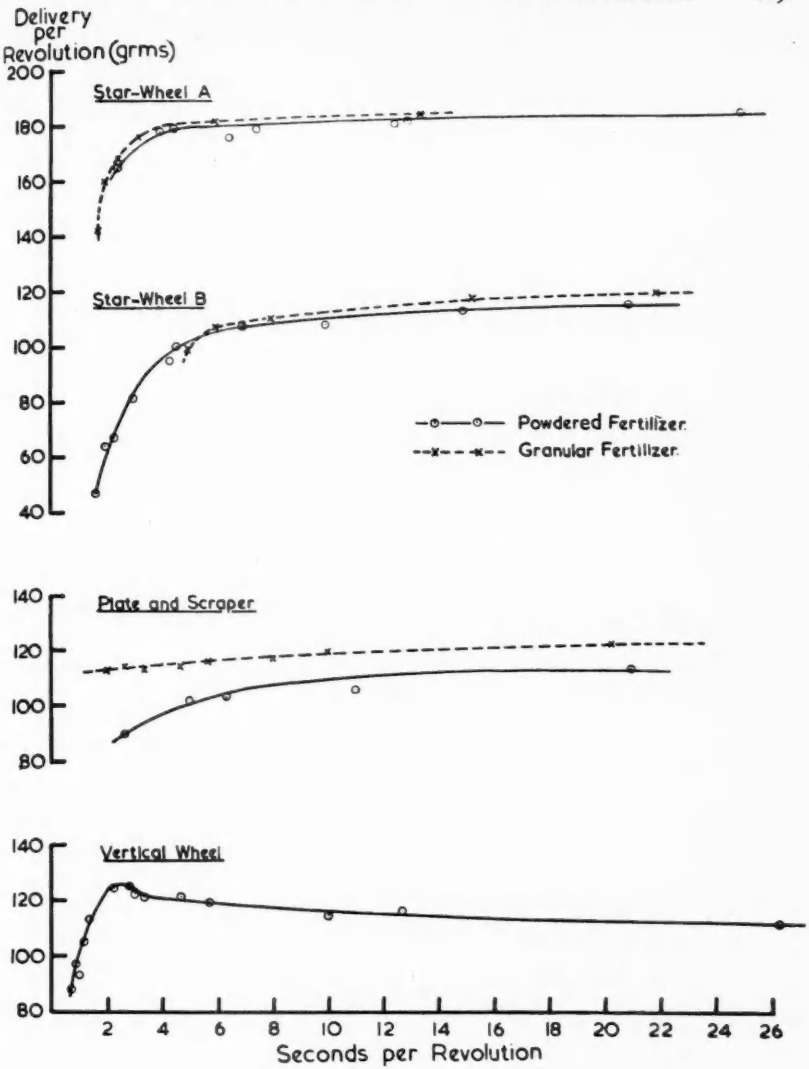


FIG. 8. Effect of speed on delivery rate.

The amount which the piston rises for one revolution of the cylinder is fixed and the rate at which it rises is directly proportional to delivery rate in stationary tests. (In the field, compacting of fertilizer caused by jolting over rough ground reduces low delivery rates proportionally more than high rates.)

Delivery from other mechanisms is varied both by altering the speed of moving parts that displace fertilizer, and by altering the size of the aperture (gate) which allows fertilizer to move from the hopper. There may be advantages in using one or other of these means of regulating delivery under different conditions. The effect of different gate-openings on delivery from the star-wheel and plate-and-scraper was determined in the tests described above (Figs. 6, 7). Further tests were made on the star-wheel, plate-and-scraper, and vertical-wheel model machines. The mechanisms were rotated at different speeds and the fertilizer delivered by several revolutions was weighed. The data are examined in Fig. 8 by plotting delivery per revolution against the speed of the wheel.

Each type of mechanism had a critical speed below which delivery rate was directly proportional to the speed of the rotating parts. At higher speeds delivery for each revolution decreased rapidly with increasing speed. The critical speed for plate and star-wheel model machines was approximately $\frac{1}{6}$th revolution per second. Delivery from the vertical wheel was low at very high speeds, rose to a maximum at about $\frac{2}{3}$ths revolution per second and then decreased as the wheel speed decreased.

Periodicity in delivery.—Some drills exhibit a regular cycle of low and high delivery rates depending on faults in construction (such as distortion of a delivery plate). Such a cycle may be reduced by changing the imperfect component. Other mechanisms, such as star-wheels, have an inherent periodicity in delivery [1]. As a star-wheel travels forward with a load of fertilizer it moves over the hole in the bottom plate, thus allowing fertilizer to fall down the delivery tube (Fig. 1). As soon as the tooth uncovers part of the hole, delivery commences and quickly reaches a maximum rate; the rate then falls as the fertilizer between the teeth empties and may be zero momentarily as the next tooth passes over the opening in the bottom plate. Most manufacturers reduce the periodicity by cutting an oval-shaped hole with a pointed end, but variations in delivery cannot be entirely eliminated.

Variations in delivery from the plate-and-scraper and from the star-wheel (A) were examined by collecting the output from the model machines on a paper band which travelled forward 4 in. per second. The fertilizer deposited on consecutive lengths of 1 in. was collected and weighed (1-in. travel of the paper band corresponds approximately to 1 ft. travelled over the ground by a distributor drawn at 3 miles per hour). The weights of fertilizer (expressed as percentages of the mean delivery rate) were plotted against the distance travelled (Fig. 9).

There was some variation in delivery from the plate-and-scraper, powdered fertilizer being delivered more uniformly than granular material. Output from the star-wheel varied according to the position of a tooth in relation to the delivery hole under the wheel; the curves for granular and powdered fertilizer were similar, output ranging from 40 to 140 per cent. of the mean rate.

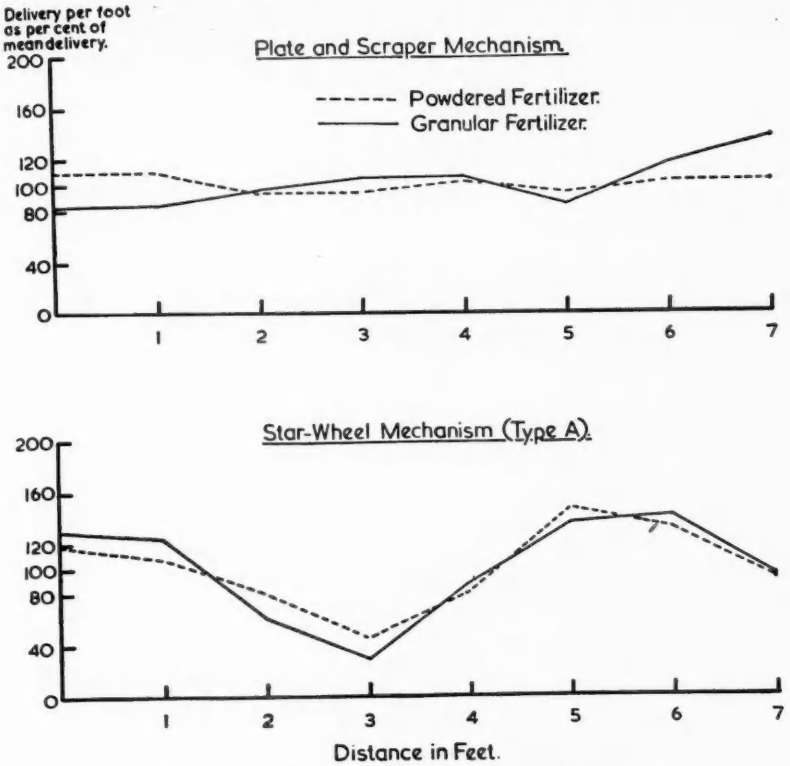


FIG. 9. Variations in fertilizer delivery rate with distance travelled.

Discussion

Although the top-delivery cylinders were fitted to a drill constructed solely for experimental work, they were not entirely satisfactory since delivery was not constant as the cylinders were emptied. Initial output was always low due to compacting of the fertilizer by upward pressure of the piston; this effect was more serious when damp fertilizers were used. Delivery of dry fertilizer rose sharply during the first few revolutions. The peak noticed immediately before delivery became steady is a feature of such machines and is due to the interaction of forces tending to compact or to deliver fertilizer. The National Institute of Agricultural Engineering [4] record a similar peak in delivery from a top-delivery distributor. With fertilizer in good condition output from the first 10 revolutions of the cylinder should be rejected before starting work on an experiment. If the soil is at all rough, jolting will consolidate the fertilizer; the drill should be given a preliminary run to allow some settling to take place.

Model machines incorporating either a plate-and-scraper or a thick star-wheel (A) delivered fertilizers sufficiently uniformly for most experimental work. Delivery was irregular when very narrow gate-openings were used, the opening chosen should always be much larger than the diameter of the largest particles in the fertilizer.

Delivery from the thin star-wheel (B) was fairly constant when the gate was closed but, with the gate open, delivery was very irregular. The wheel was a rough casting and did not fit the bottom plate of the hopper at all well. Fertilizer worked under the wheel and by forcing upwards altered the size of the gate-opening and consequently varied the delivery rate. With such a mechanism, the gate should be closed when possible; experimenters may improve the performance of a drill by resetting individual gates and wheels and by reducing any high-spots on the castings.

Delivery by the plate-and-scraper and by star-wheel model machines fell rapidly after three-quarters of the hopper capacity had been delivered. The last portion of the fertilizer in a gravity-fed hopper should not be applied in an experiment, and the hopper should be refilled when little more than half of the fertilizer has been used.

Tests on the vertical-wheel model machine showed that such mechanisms may be most unreliable, particularly with powdered fertilizers. Only a small portion of the wheel perimeter was in contact with fertilizer and the spaces between the teeth were filled from the bulk of fertilizer entirely by gravity. Granular fertilizer rolled down to the wheel and delivery was moderately uniform. A cavity formed in powdered fertilizer and only a small fraction of the total capacity of the hopper was delivered. Distributors fitted with such a mechanism are likely to be satisfactory only with granular fertilizer, and when an efficient agitator is fitted that works to the full width of the hopper. In contrast, the plate and star-wheels were satisfactory in these tests since half of their surface revolved in the hopper and agitated the mass of fertilizer continually. Star-wheels are forced through the bulk of fertilizer and the spaces between the teeth become uniformly filled.

Speed had an important effect on delivery from wheel and plate model machines. When fertilizer is delivered by the surface of a horizontal wheel, increasing the speed increases the tendency for 'slip' between the wheel surface and the fertilizer, particularly if damp fertilizer is used. The spaces between the teeth of toothed wheels are not adequately filled at high speeds. Settings on a drill should be chosen within the range where delivery is directly proportional to the speed of the mechanism.

There were extreme variations in the amounts of fertilizer delivered by a star-wheel to consecutive intervals along the row. This behaviour is the worst feature of a mechanism which is widely used in commercial drills and if well made can be very satisfactory for distributing fertilizer in experiments. Adjacent sections of row receive different quantities of fertilizer which may give uneven growth or cause damage to germination when excessive doses of soluble salts are in contact with the seed. Such variations may be at a maximum with well-conditioned granular

fertilizers that fall rapidly through the delivery tubes. Powders fall more slowly down the tubes and delivery may tend to become more even.

Before any field work on an experiment is attempted with an unfamiliar distributor a series of calibration tests should be made. The drill may be jacked up and delivery of the fertilizers to be used should be measured for the different gate-settings and speeds provided by the manufacturer. Output from the individual units should be tested since gate-settings are not always uniform and imperfect wheels may have been fitted. Badly made or flawed units should be replaced; removal of high-spots on wheels or plates and resetting of the gates frequently leads to more uniform delivery. After choosing suitable speeds and gate-settings further calibrations should be made while running the drill over the field where it is to be used. (Jolting affects gravity-feeds and increases delivery rates; stationary calibrations of some drills may be misleading.)

Experimenters should always use fertilizers in the best possible physical condition. In these tests granular fertilizer was more satisfactory than powder of the same composition; other things being equal granular fertilizers are to be preferred to powders. If powdered fertilizers must be used they should be stored under good conditions and if necessary dried before use. Good storage depends on several conditions. The number of bags in a pile should be limited since pressure may cause setting of fertilizer in the lower bags. Storage on a wooden floor or on duckboards prevents moisture rising through the pile of bags. Ideally fertilizers should be stored in a room where temperature and humidity are controlled. Fertilizers do not easily deteriorate in condition if they are stored in sealed packages to prevent free movement of air between the particles. Paper bags having bitumen-sealed layers are much more satisfactory than jute bags. Tests to determine the most satisfactory types of paper bags and the behaviour of fertilizers during storage have been described [9]. Packages should not be opened until the fertilizers are to be used. Even with these precautions it may be impossible to drill very hygroscopic powders (such as muriate of potash) unless they are diluted with inert material since they absorb moisture from the air when placed in the hopper of a distributor.

Summary

In field experiments fertilizers must be applied with greater precision than is necessary in general farm practice. Three mechanisms commonly fitted to commercial fertilizer distributors were tested in models to determine their suitability for applying experimental dressings. Tests were also made on a top-delivery drill built specially for experimental work.

Machines incorporating revolving plates or star-wheels delivered granular and powdered fertilizers uniformly in laboratory tests. A thick star-wheel delivering fertilizer mainly from the spaces between the teeth gave more constant rates than a thin wheel which delivered fertilizer both between the teeth and on the surface of the wheel. A vertical-wheel model machine delivered fertilizers very unevenly and drills

incorporating such a mechanism would not be satisfactory for use in field experiments.

Granular fertilizer was generally delivered more uniformly from all machines than a powder of the same composition. Powdered fertilizer absorbed much more water from the air than granular material. All the mechanisms tested delivered dry powder more regularly than damp powder.

Irregular delivery of well-conditioned fertilizer is due to several causes. Alterations in bulk density of the material affect all conventional distributors. Where the surface of a wheel or plate is used to dispense fertilizer from the hopper, 'slip' between the wheel surface and the fertilizer may be caused by high speeds or by using damp fertilizer. Gravity-feed from a hopper to a toothed wheel is likely to be unsatisfactory unless free-flowing fertilizers are used and an efficient agitator is fitted. Efficient agitation may be secured by arranging horizontal wheels so that they occupy a large part of the hopper bottom. Gravity-fed mechanisms may not deliver constant amounts of fertilizer after three-quarters of the total capacity of the hopper has been delivered. Distributors incorporating wheels having widely spaced teeth deliver different amounts of fertilizer to consecutive lengths of row since delivery is governed by the position of the teeth of the wheel in relation to the hole that allows fertilizer to fall down the delivery tube.

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THE PHOSPHATE RESERVES IN SOME OLD PERMANENT PASTURE PLOTS

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PHOSPHATE fixation in soil has been much studied and opinion is divided concerning its mechanism; but the fact remains that a large proportion of the phosphate added to the soil in fertilizers is fixed and apparently irrecoverable by growing crops. Daubeny [1], more than a century ago, showed that only a fraction of the nutritive elements present in soil is available to the plant for growth and reproduction. A few years later, Way [2] demonstrated that an aqueous solution of sodium phosphate, and a dilute sulphuric acid solution of calcium phosphate, lost all the detectable phosphate when passed through soil. Subsequent field experiments have shown that the total phosphorus-content of a soil bears little relationship to the response of crops to further additions.

According to Russell [3] the fraction of added phosphorus recovered in crops on arable land is never more than 25 per cent., and a similar figure has been given by Williams and Stewart [4] and by E. M. Crowther [5]. It is thus obvious that, on land under regular treatment with phosphatic fertilizers, large reserves must accumulate. The best known investigation of these reserves is that of Dyer [6], who studied exhaustively the after-history of the phosphoric oxide applied to the Broadbalk Wheat Field at Rothamsted for over 50 years. Apart from some work done by Hanley [7] on the Tree Field plots at Cockle Park, there appears to have been no counterpart on grassland of Dyer's investigation on arable. Unfortunately, Hanley's work was limited in scope: his studies of profile distribution extended only to 9 in., and his results refer only to HCl-soluble phosphoric oxide and are difficult to interpret.

The distribution, and possibly the availability of the phosphate reserves, in a pasture soil may well differ from those in arable land. In the former, the sward itself holds an appreciable amount of phosphoric oxide, so that the immediate effect of ploughing will probably be to increase the phosphate-content of the soil proper. On arable land, added phosphatic fertilizers are admixed to ploughing depth; in pasture, broadcasting will obviously tend towards concentration in the surface layer.

The Tree Field plots at Cockle Park have received regular and periodic dressings of phosphate for over 50 years, and the live-weight gains made by grazing sheep, since Somerville initiated his 'Manuring for Mutton' experiment in 1897, are all on record [8]. It is thus possible to assess the weights of phosphorus which have been removed from the plots. Phosphates have been applied in different forms—basic slag, superphosphate, and as cake fed to sheep. Lime, and fertilizers supplying potassium and nitrogen, have been applied on certain of the plots. The

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reaction changes effected by these additional fertilizers provide useful material for a study of the effect of pH and base-status on phosphate availability.

The present investigation was undertaken to ascertain the magnitude of the phosphate reserves in these plots, to study the profile distribution by analysis of the soil at various depths, and to estimate the availability of the phosphate by chemical means as well as by pot experiments. It was also proposed to investigate the effect on phosphate availability of such factors as reaction, base-status, and nutrients applied additionally. Finally, an attempt was made to prepare a phosphate balance sheet for the particular plots under investigation, taking into consideration the quantities supplied in fertilizers, and those estimated to have been removed by grazing stock.

Experimental

The Tree Field experiment has often been described, and it suffices to say here that the soil, which is typical of large areas in the County of Northumberland, is a strong clay loam derived from Boulder Clay overlying a sandstone of the Millstone Grit Series. Chemical analyses of the plots were made and published by Collins [9, 10] many years ago.

Only sheep occupy the plots for a period of 14 weeks between May and August or September; during the autumn or early winter they are stocked with cattle and grazed bare. As these cattle consist of dry cows, it may be assumed that they remove no appreciable amount of phosphate from the plots.

Those of the plots which have been used in this investigation have been manured in substantially the same way since the original experiment began. The following table shows the treatments applied, and the total amounts of nitrogen, phosphoric acid, and potash added per acre during the period 1897–1945.

TABLE 1. *Manurial Treatment of Tree Field Plots*

Plot no.	*Treatment*	*Total in lb. per acre applied from 1897 to 1945*		
		N	K_2O	P_2O_5
1	300 lb. high-protein concentrate fed annually to sheep for 3 successive years followed by 3 years without concentrate	763	157·5	270
4	5 cwt. basic slag every third year	..	..	1,600
5	7½ cwt. superphosphate every third year	..	..	1,600
6	Untreated	..	..	..
7	5 cwt. basic slag and 100 lb. muriate of potash every third year	..	850	1,600
8	5 cwt. basic slag and 1 ton lime every third year	..	..	1,600
9	5 cwt. basic slag and 112 lb. nitrate of soda every third year	329	..	1,600

As the use of an auger to collect soil samples between precisely determined depths was obviously impracticable, the following procedure

was adopted. A pit at least 24 in. deep was dug, one face cleaned down, and the samples cut out at the requisite levels with a large knife. Four 2-in. samples were taken down to a depth of 8 in.; beyond this, and to a depth of 23 in. samples were 3 in. thick. Four such series of samples were collected from each plot, every pit being located at random and all sampling done within a few days. Samples were air-dried, ground, and passed through the 2-mm. sieve in the usual way.

Results

Total phosphoric acid was determined both by Robinson's method of extraction with hydrofluoric acid [11], and by the Williams method of fusing with sodium carbonate [12]; very good agreement between the two was obtained. Table 2 gives the values for total phosphoric oxide in samples taken at various depths on the 7 plots investigated. Each of these values is the mean of 4 samples.

TABLE 2. *Total P_2O_5 in mgm. per 100 gm. of Air-dry Soil*

Depth	*Plot 1*	*Plot 4*	*Plot 5*	*Plot 6*	*Plot 7*	*Plot 8*	*Plot 9*
0–2	126	205	228	101	190	220	253
2–4	92	141	150	89	140	168	158
4–6	81	101	106	84	110	127	118
6–8	75	82	92	68	98	97	92
8–11	66	65	65	63	67	68	68
11–14	51	56	57	56	62	58	47
14–17	53	57	54	64	57	50	44
17–20	51	68	59	69	60	61	52
20–23	63	79	85	78	66	72	64

Thus the depth-distribution of the total phosphoric acid is similar in all plots, the values falling consistently to a depth of 14–17 in. after reaching approximately the same level at 8–11 in. As would be expected, Plot 6 shows a gentler gradient than the others. It is therefore obvious that all the added phosphate has been fixed within a range of 11 in., and by far the greater part of it within a few inches of the surface. Below 17 in. the phosphoric-oxide content increases again in all plots.

Table 2 indicates that, of the plots receiving phosphatic fertilizers, some have accumulated more phosphorus in the top 8 in. than have others; a statistical test did not, however, reveal any real differences. The phosphoric oxide in the soil at any depth in Plot 4 (basic slag only) was not significantly different from that in the soil at a corresponding depth in Plot 5 (superphosphate), or in Plots 7, 8, or 9, which had received supplementary treatment in addition to dressings of basic slag. The maximum depth of penetration of the phosphoric oxide has been the same in all cases, i.e. 11 in., and has not been increased by dressings of potash, of nitrate of soda, or of lime. These findings are at variance with the results obtained by Dyer [6], who showed that the application of sodium, potassium, and magnesium salts to the Broadbalk Wheat Field at Rothamsted resulted in a descent of the added phosphoric oxide into the second and even into the third 9 inches.

During the experiment, Plot 1 has received 270 lb. P_2O_5 in the form of cake fed to sheep, and the phosphate-content of the soil is therefore slightly higher than that of Plot 6, being 0·0935 per cent. P_2O_5 for the top 8 in. in comparison with 0·0855 per cent. in the latter. The phosphoric oxide derived from cake has leached to about the same depth as the mineral phosphates applied elsewhere.

The total amount of phosphate that has been added to these plots during the past 50 years is known, and as figures for live-weight increase for the whole period of experiment are available [8], a fair estimate of the phosphoric oxide that has been removed as mutton can be made. Assuming, therefore, that the soils of all the plots were uniform throughout (and Collins's survey [13] appears to justify this assumption), and that all were at the same phosphate-level as the unmanured plot when the 'Manuring for Mutton' experiments were initiated, it is possible to calculate the total amount of P_2O_5 in lb. per acre which should have accumulated in each plot. A comparison can then be made between these calculated figures and those obtained by chemical analysis. Henry and Morrison's value [14] of 1·14 per cent. P_2O_5 was used for calculating the total amounts of phosphoric oxide which have left the soil from the different plots in the form of mutton. Table 3 shows the total P_2O_5 that should be present in different plots to a depth of 11 in., which is the maximum depth of penetration of the added phosphate. For this calculation, the weight of 1 acre of soil to 11 in. depth was taken as 2,897,700 lb.

TABLE 3. *Phosphoric Oxide (in lb. per acre) in Soil to Depth of 11 inches*

Plot no.	*Estimated from known additions and removals*	*Found by analysis*	*Deficiency*	*% P_2O_5 accounted for*
1	2,524	2,492	32	98·7
4	3,846	3,296	550	85·7
5	3,849	3,549	300	92·2
7	3,849	3,374	475	87·7
8	3,848	3,761	87	97·7
9	3,850	3,803	47	98·8

Thus on 3 of the plots (Nos. 1, 8, and 9) virtually all the added phosphate can be accounted for, but in the remaining three (Nos. 4, 5, and 7) the differences between the actual and the calculated amounts are considerable. In his work on the Broadbalk Wheat Field at Rothamsted, Dyer [6], on analysis of soils from 6 plots (to a depth of 9 in.), accounted for about 86 per cent. of the added phosphoric oxide, and he thought the difference was due to some of the added phosphate having been leached below the 9-in. level. Such an explanation would not apply in the present case, for the depth distribution on Tree Field clearly indicated that there had been no leaching below 11 in. How then are those losses of applied phosphoric oxide to be accounted for? The possibility of its removal—soon after application—by surface washing has been considered, but such loss seems improbable. The only possible explanations are: (1) that Henry and Morrison's value for the P_2O_5-content of the carcass is

too low under the conditions of the experiment; and/or (2), that the additional cattle-grazing, which has followed the experimental period of sheep-grazing, did in fact remove small amounts of phosphoric oxide.

Available phosphoric acid as measured by chemical methods.—The foregoing results for total phosphoric oxide do not indicate the real phosphate-status of the plots, if this be regarded as the ability of the soil to supply phosphate to a growing crop. To measure the so-called 'available' phosphoric oxide, several chemical methods were to hand; alternative to these it was thought that an assessment of availability might be possible by measuring the growth of plants in soils from the various plots. Two chemical methods, viz. that of Dyer [15], and the acetic-acid extraction procedure of Spurway [16], were used. The determination in the Dyer's citric-acid extract was carried out by the method of Deniges as modified by Trinder [17], and in the acetic-acid extract by that of Williams and Stewart [18]. The mean phosphoric-oxide contents, soluble in 1 per cent. citric acid and in 2·5 per cent. acetic acid, of soils from the top 8 in. of the different plots are given in Table 4, which includes also the pH values.

TABLE 4. *Milligrams of P_2O_5 per 100 gm. of Top 8 in. Air-dry Soil*

Plots	*Soluble in citric acid*	*Soluble in acetic acid*	*pH of soil*
1	6·5	0·4	5·29
4	15·4	3·0	5·75
5	23·4	2·7	5·31
6	6·5	0·5	5·12
7	17·8	2·3	5·74
8	37·1	9·2	7·51
9	26·9	6·0	6·08

It is seen that whereas extraction with citric acid gives values some 5 to 15 times higher than does acetic acid, the plots are in approximately the same order as regards phosphate availability. Although Plot 1 has received some phosphate in the form of cake fed to sheep, its available phosphoric oxide is as low as that of the unmanured plot (No. 6). Plots 4, 5, and 7 show little variation, differences between any two, with either method, being non-significant at 5 per cent. level. Dyer [6] showed that dressings of sodium, potassium, and magnesium salts on the Broadbalk Wheat Field at Rothamsted caused applied superphosphate to remain in a more available condition. Application of potash to Plot 7 of Tree Field, however, does not appear to have affected any appreciable change in phosphate availability. It should be noted that this land is not naturally deficient in potash. Plot 9, which has received nitrate of soda in addition to basic slag, contains more phosphoric oxide than Plot 4, as measured both by the citric-acid and acetic-acid methods; how far this increase is due to the application of the sodium salt is also uncertain, since the pH of the soil is higher, and soil reaction alone may be a major factor in the solubility of the phosphoric oxide. Plot 8 has

a still higher available phosphoric-oxide content, and this may be due to the higher basicity of the soil, which is on the alkaline side of neutrality.

Available phosphoric oxide as measured by pot experiments.—The use of pot experiments for measuring the amounts and availability of the phosphate reserves in this soil is open to the criticism that other variables may influence dry-matter yields. Thus there might be nitrogen effects on Plots 1 and 9, although on the latter plot this is extremely unlikely, as the most recent application of nitrate of soda was made 2 years before the date of the present investigation. The effect of past dressings of potash might become evident in the soil from Plot 7, and the relatively large amount of lime used on Plot 8 during more than 50 years of experimentation could exercise a direct effect on yields quite apart from any influence it may have on phosphate availability. It was, nevertheless, considered worth while to undertake an experiment in which some soil from each plot would be cropped without further treatment, and some after receiving added superphosphate.

Soil was obtained from the appropriate plots of Tree Field by taking, at random, a large number of spits to a depth of 8 in. Each plot was represented by 10 pots, half of which were treated with superphosphate at a rate equivalent to 5 cwt. per acre. Radish (*Raphanus sativa* L.) was used as the experimental plant, as it is quick growing and responsive to phosphate. The plants were harvested after 1 month when they were fully mature, and dried to constant weight. The phosphoric oxide of the dry matter was then determined in the bulked replicates. As it was felt that further information on phosphate availability might be obtained by cropping a second time, the pots were resown immediately after harvesting. The results of both trials are given in Table 5.

TABLE 5. *Mean Yield in grams per Pot (20 plants in each)*

	First crop				*Second crop*	
	Untreated		*Treated*		*Untreated*	*Treated*
Plot	*Dry matter*	*% P_2O_5 in D.M.*	*Dry matter*	*% P_2O_5 in D.M.*	*Dry matter*	*Dry matter*
1	0·72	0·44	1·42	1·29	0·99	1·15
4	2·96	0·93	3·03	1·33	1·47	1·64
5	1·97	1·23	2·43	1·66	0·68	0·89
6	0·53	0·43	1·08	1·43	0·58	0·57
7	2·66	0·81	3·01	1·32	1·10	1·36
8	2·44	0·95	2·51	1·27	1·20	1·27
9	2·72	0·84	3·06	1·23	1·35	1·69
S.E. of dry matter 0·115				S.E. of dry matter 0·043		

At the first cropping the yield of untreated soil from Plot 4 was significantly higher than the yield from either of Plots 5 or 6. No significant difference was noticed between the yields of Plots 4 and 7, or of Plots 4 and 9; but Plot 4 produced more dry matter than Plot 8. Since neither Plot 9 nor Plot 7 gave a higher yield than Plot 4, it may be assumed

that any nitrogen effect in Plot 9 or potash effect in Plot 7 was insignificant. There was no difference in yield between Plots 6 and 1 at 5 per cent. level. Of the plots receiving basic slag alone or in addition to other nutrients, 7 and 9 show responses to further treatment with superphosphate which barely attain significance at 5 per cent. level. Increments on Plots 5 (superphosphate), 1 (cake fed to sheep), and 6 (unmanured) are clearly significant.

The superiority of Plot 4 to Plot 6 was expected and can be explained; two factors have probably been concerned in it, viz. lime-status and available-phosphate content, and of these two the latter may be the major one. The past treatment suggests that Plot 4 will contain very much more available phosphoric oxide than Plot 6, and the chemical techniques employed amply confirm this. Further evidence of the poor phosphate-status of Plot 6 is provided by the results accruing from the addition of superphosphate, which has given a highly significant increase in yield.

The results for Plot 5 are much more difficult to explain. It is a fact that this plot has always been held to produce a sward inferior to those existing on any of the slagged plots. Further evidence of its low productivity is provided by the live-weight increase figures [8], and by the results of the grass-cutting work of Thomas and his co-workers [19]. Considered singly, the foregoing observations and results do not appear to be very conclusive; collectively, they do suggest that the use of superphosphate has been less effective than that of basic slag, for which there are several possible explanations. It may be due to the direct effect of a more acid soil reaction, although a pH of 5·3 would not seem to be excessively low for such a crop as radish. Both the Dyer and the acetic-acid extraction methods may have failed to provide a true reflection of phosphate availability; a comparison of the results of adding superphosphate to Plots 4 and 5 suggests that they have. As Thomas and Elliott [20] have shown that both nitrification and nitrogen-fixing capacities on these plots are significantly correlated with reaction, the possibility of a nitrogen effect cannot be ignored. The first of these possibilities is unlikely and it may be concluded that phosphate availability is, in fact, lower on Plot 5 than on Plot 4, and that this factor is reinforced by a nitrogen effect.

Consideration of results obtained from other plots shows that neither Plot 7 nor Plot 9 has produced a higher yield than Plot 4. That the soil of Tree Field is not naturally deficient in potash is indicated by the work of Collins [9] and of Thomas [21]. Potash is therefore unlikely to interfere in any comparison of Plots 4 and 7. These two plots have the same reaction, and the available-phosphoric-oxide figures, as determined both by the Dyer and the acetic-acid extraction methods, are very close. Furthermore, the response to added superphosphate was very small on both plots. It would appear probable, therefore, that both Plots 4 and 7 contain reserves of available phosphoric acid sufficient to grow a crop without further addition, and that these reserves are approximately of the same magnitude.

Plot 9, which has received nitrate of soda as well as basic slag, shows no superiority to Plot 4 as judged by dry-matter production. As the

last application of nitrogen to the former had been made two years previously, a nitrogen effect was not to be expected. The available phosphoric oxide as determined both by Dyer's method and by acetic-acid extraction is, however, markedly higher than on Plot 4, and because of this a higher yield of dry matter would not have been surprising. Here again the response to added superphosphate, although just reaching significance at the 5 per cent. level, is so small as to suggest that the reserve of available phosphorus would probably suffice to produce one crop.

The lower dry-matter yield from Plot 8 is not easily accounted for. Available phosphoric oxide, as measured by chemical methods, is markedly higher on this plot than on Plot 4, and neither shows a response to added superphosphate. The pH of Plot 8 (7·50) is relatively high as compared with that of Plot 4; whilst the direct effect of alkaline conditions on the growth of radish is not known with certainty, it is not improbable that it has been partly responsible for the low dry-matter yield on Plot 8. An indirect effect, involving immobilization of one or other of the minor elements, may also be concerned. It is conceivable that sub-acute deficiencies result in reduced yields without giving rise to any recognizable and obvious deficiency diseases. Nitrogen could not be a limiting factor since according to Thomas and Elliott [20] the nitrification and nitrogen-fixing capacities of the soil are high as compared with those of soils from other plots. It must be concluded that pot experiments have failed, on this particular plot, to confirm the results obtained by the chemical methods used; it should be added, however, that neither does it vitiate them.

Plot 1 is obviously distinctly poor, and the yield of dry matter in the pot experiment was little higher than that from the unmanured plot. The former has received phosphate only in the form of cake fed to sheep, the total quantity applied during the whole period of 50 years being 270 lb. P_2O_5 per acre as compared with 1,600 lb. added to other phosphated plots. That the greater part of this phosphorus has been rendered unavailable is suggested by the low phosphate-contents of the citric-acid and the acetic-acid extracts, which are not very different from those obtained on Plot 6. Additional evidence of this is provided by the highly significant increase in yield resulting from the addition of superphosphate. The reaction of the soil of Plot 1, it should be remembered, is almost the same as that of Plot 6.

The assimilation of added phosphate by plants depends to some extent upon the initial available phosphoric oxide in the soil; in a soil rich in it, the increase in P_2O_5 in the dry matter of the plant resulting from addition of further quantities of a phosphate fertilizer will be low, whereas in a soil initially deficient in it this increase would be considerable. Phosphate-uptake, therefore, is another means whereby deficiency or otherwise of available phosphoric oxide in a soil may be measured. In the present investigation Plots 1 and 6 showed a very high increase in the uptake of phosphate on treatment with superphosphate, thus indicating low initial available-P_2O_5 contents. In other plots, which have for long received periodical dressings of phosphate fertilizers, the increases in P_2O_5-content of the dry matter were relatively small,

although no distinction could be made between slag (Plots 4, 7, and 9), superphosphate (Plot 5), and slag and lime (Plot 8) plots.

At the second cropping, plots are, in general, in the same order of productivity as in the first trial, and there has been a well-marked decline in yields. Among the untreated soils, Plot 7 has shown a statistically significant inferiority to Plot 4, whilst Plot 1 has yielded more heavily, relative to Plots 5 and 6, than on the first occasion.

Plots 1, 4, 7, and 9 showed significant differences between treated and untreated soils, the response to added superphosphate on the first two being relatively small. Although the first crop of radish had removed only 5 per cent. of the added P_2O_5 from the soil of Plot 6, there was no further response on cropping a second time; the obvious explanation in this case seems to be that the added superphosphate had been completely fixed by the soil, which is distinctly more acid than that of any of the slagged plots. The well-marked increase in yield from the treated soil of Plot 5 must be due to the effect of residues from the superphosphate added during the first trial. The incompleteness of fixation in this case, despite the soil having a pH value little higher than on Plot 6, is probably due to the heavy dressings of phosphate received earlier; the fixation of a further quantity of phosphate would be slower, and would probably be incomplete within a month of its application.

Conclusions

The results of the investigation described have practical implications of some importance. In the event of ploughing and cropping old grassland of the type studied, the following facts would be relevant to the manurial policy adopted:

Of previously added but unused phosphate, approximately 98 per cent. remains in the surface 8 in. of soil, and is within ploughing depth; an arable crop would thus have easy access to such of it as might be available.

On land which has received basic slag for many years, with or without supplementary fertilizers (Plots 4, 7, 8, and 9), it should be possible to grow a first crop without the further addition of phosphatic fertilizers. Rather lighter crops could be expected on land which has received lime in addition to basic slag (Plot 8), but not because phosphorus has been lost from the surface soil or because the availability of that phosphorus has been reduced.

Where little or no phosphorus had been applied for many years (Plots 1 and 6) a reasonable dressing of a phosphatic fertilizer would be necessary. Such application could be expected to give an immediate response, but the residues would be quickly fixed and rendered completely unavailable. Treatment with phosphatic fertilizers would therefore have to be repeated annually for some time.

The long-held view that superphosphate is not a good source of phosphorus on land of this class has been confirmed. Where superphosphate has been used instead of basic slag in past years, even though in equivalent amount, a first crop of optimum size could not be grown without added phosphorus.

Summary

1. The extent, availability, and depth distribution of the phosphate reserves on Plots 1, 4, 5, 6, 7, 8, and 9 of Tree Field have been studied.

2. The total phosphorus-content of plots which have received basic slag or superphosphate showed no significant differences at corresponding depths down to 23 in.

3. The maximum depth of penetration of the phosphorus was the same on all plots, and had not been increased by dressings of potash, nitrate of soda, or lime.

4. On three of the plots almost 100 per cent. of the phosphorus added during the period of the experiment was accounted for after deducting the calculated amounts removed by grazing stock. Percentage recoveries were, in general, higher than those obtained by Dyer on the Broadbalk Wheat Field.

5. Apparent losses of phosphorus were considered to have been due to an under-estimate of the amounts removed by grazing stock.

6. The availability of phosphorus reserves has been measured by chemical methods and by pot experiment.

7. The latter technique provided evidence that plots which had received basic slag alone or in conjunction with other fertilizers would produce a first arable crop without further fertilizer treatment.

8. The relatively high values for available phosphorus found on Plots 5 (superphosphate), 8 (basic slag and lime), and 9 (basic slag and nitrate of soda) by chemical methods were not confirmed by pot experiment.

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STUDIES ON THE EGYPTIAN BUFFALO: I. AVERAGE AGE AND CALVING INTERVAL

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THE buffalo is generally considered to be the most suitable animal for milk production in Egypt. In the most recent census the total population was just over 750,000 buffalo cows and about 500,000 buffalo bulls. The cattle population is similar in number. The density of the buffalo is about 0·23 per acre of cultivated land and this figure with that for cattle gives a very high value for the stock density. This is mainly due to the use of the animals for ploughing and general farming operations. There are no breeding herds in the general sense of the term except on university or government farms. Some milk producers near to the towns may keep unrecorded flying herds, but the average farmer keeps just one or two buffaloes. A communal bull is the most common method of getting the cows in calf. Legislation has been enacted forbidding the slaughter of males until they reach 3 years of age, in order to avoid inbreeding consequent on the use of a limited number of sires, and also to avoid the slaughter of potentially good sires before they could have progeny. The previous tendency had been to kill the calves very early as they provided a high-quality veal. The buffalo has definitely become adapted to Egyptian conditions and can utilize a large amount of coarse roughage and produce a fair amount of milk with a high fat-content.

The Different Types of the Egyptian Buffalo

The Egyptian buffaloes are usually thought of as falling into four distinct types, although the genetic differences between them are not at all certain. The four types are:

(*a*) The Menoufi, described by Zaki [1], are used in the Menoufia province, the southern part of the Nile Delta.
(*b*) The Beheri type, studied by El Sheikh [2], mainly in the Behira province.
(*c*) The Baledi.

These three types comprise the population in lower Egypt. Although they can be roughly distinguished by their general appearance, we have found no actual differences between them in measurements.

(*d*) The Saïdi type, found in the Saïd (Upper Egypt). This is a smaller type than the others, possibly through shortage of food, but is very hardy and well adapted to climatic conditions.

A detailed analysis of the differences between the types seems desirable in order to find out whether the classifications have any genetic meaning. The water buffalo of India has recently been discussed by Phillips [3].

The chief function of the buffalo is milk production, most of which is made into soft cheese and *ghee*, as the liquid-milk trade is still very small.

[Empire Journ. of Exper. Agric., Vol. 19, No. 75, 1951.]

The average yield of milk in the whole country is not known. The limited number of records available from university and government farms are not representative as the animals are derived from stock selected on the basis of yield and the standard of management is probably much higher than the average. The Ministry of Agriculture herds number about 1,500 head with an average production of 400 gallons with a fat-content of 7–8 per cent. The Universities of Cairo and Alexandria have similar averages in their herds. One can only

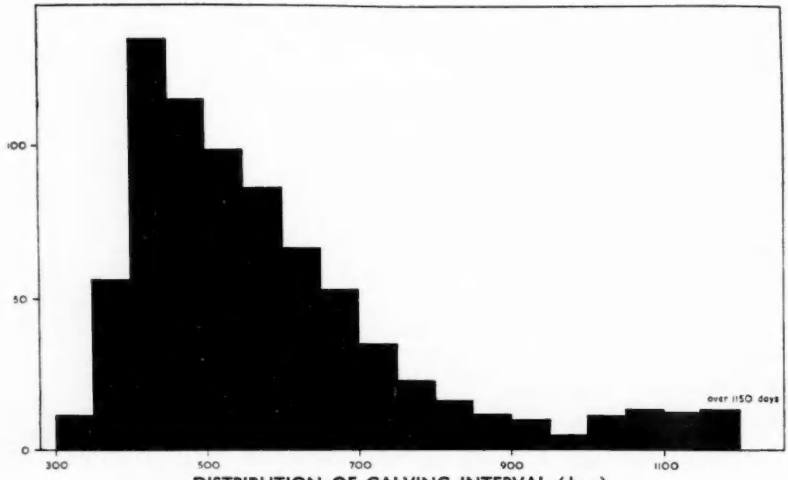


FIG. 1

estimate the average production in the country as a whole as 150–200 gals. at the most.

The genetic improvement of the Egyptian buffalo is being given increasing attention by those working with livestock. It is still not certain whether foreign breeds of cattle could not be acclimatized in the country as milk producers, although their grades with the native cattle are probably better suited than either of the parent breeds. We hope in this department to be able to import dairy breeds from Britain and the U.S.A. and study them in exactly the same conditions as the native cattle and buffaloes. In this series of papers, we intend to analyse the factors, both hereditary and managerial, affecting the performance of the Egyptian buffalo.

Calving Interval, Lactation Length, and Dry Period

The data used in this investigation have been obtained from three herds in the delta region: (*a*) the Royal Private Domaine, Edfina, near Alexandria, in the north; (*b*) the herd of this department at Shebin-el-Kom in the centre; (*c*) the Royal Agricultural Society at Bahteem, near

Cairo, in the south. These herds give, therefore, a fair sample of the different climatic conditions in which this type of buffalo is kept.

In this section of the work, 830 lactations were analysed. The average

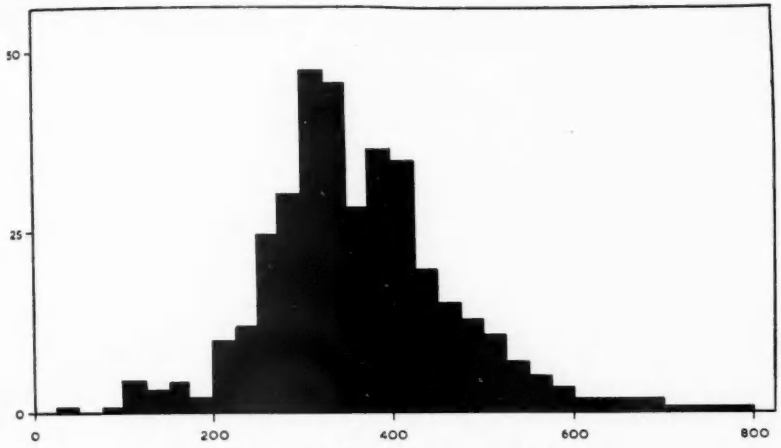


FIG. 2

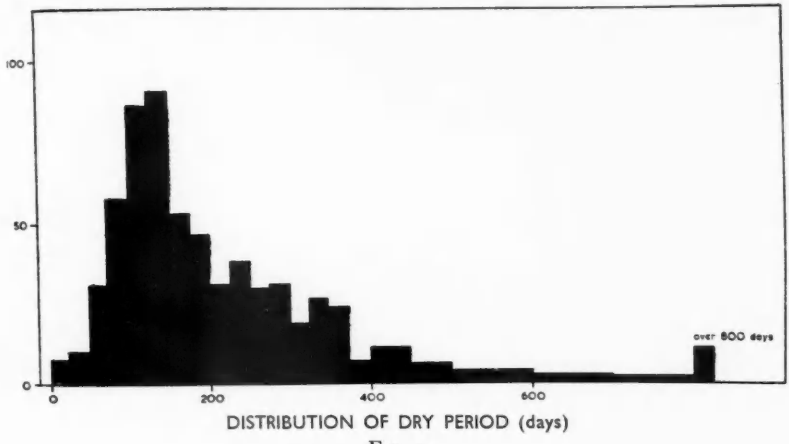


FIG. 3

calving interval was found to be 585 days and the lactation length and dry period 362 and 231 days respectively; the three distributions are shown in Figs. 1, 2, and 3. The fact that the sum of the average lactation length and dry period is slightly greater than the average calving interval is due to the cows which become sterile having a long lactation period

and, of course, an indeterminate dry period. Corresponding figures for cattle in England are a calving interval of about 390 days with a lactation length of 320 days and a dry period of about 70 days. The considerably longer calving interval compared with European cattle seems mainly to be due to an increase in dry period from 70 to 231 days. It will be seen from the distribution of dry period that 43 per cent. of the cows have dry periods longer than 200 days. Workers in European cattle have found that although very short dry periods reduce the milk yield in the subsequent lactation, the optimum dry period is about 60 days. An experimental investigation of the possibility of reducing the dry period in the Egyptian buffalo and its effect on milk yield is desirable.

It is likely that the very long calving intervals are mostly a problem of management. However, an investigation of the repeatability of the calving interval (the correlation between different lactations of the same cow) based on 715 lactations gave a figure of 0·28. This shows the calving interval is to some extent a property of the individual cow. With Ayrshires in Sweden, Johansson and Hansson [4] obtained a result not differing significantly from zero.

The Age at Calving

We obtained records from the herds mentioned above of the births of 540 calves and tabulated the age of their sire and dam when the calf was born. Rather fortuitously, the average ages of the sire and dam were both equal to 7·68 years. The number of sires in the sample was, however, rather small, so that too much importance must not be attached to that figure. The results are very much higher than for cattle in Europe, where the figures are generally 5–5½ years for the dam and 3½–4 years for the sire. The distribution of the age of the cows at calving is given in Fig. 4.

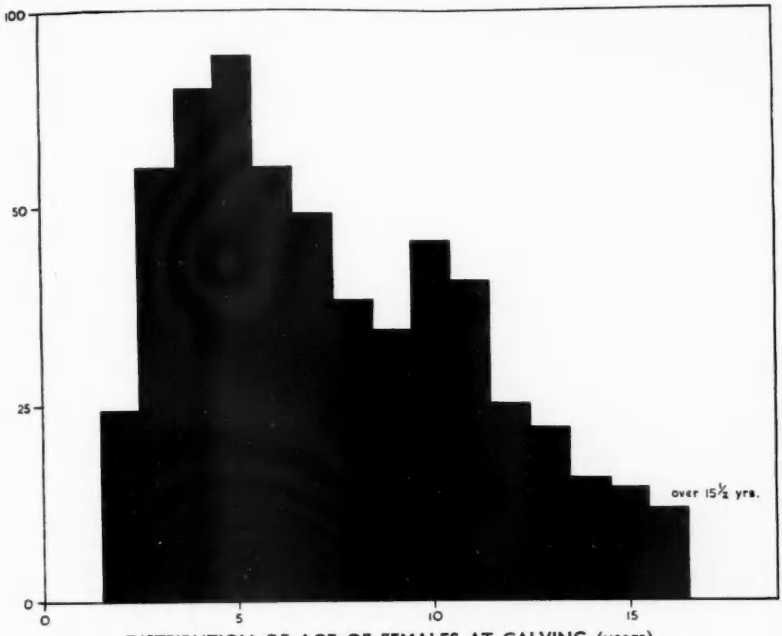
The average age of a population of milking-cows depends on three factors: (*a*) the age at first calving; (*b*) the number of calvings in the cow's life; (*c*) the calving interval.

The distribution of age at first calving for 219 animals drawn from the three herds is shown in Fig. 5. The lowest age at first calving is 22 months and the average is 38 months, compared with an average for heifers in England of 33 months. The long calving interval in the Egyptian buffalo will make the average age of cows higher for a given number of calvings. We can estimate the average age of the population in terms of times calved as

$$1 + \frac{\text{Average age at calving—Average age at first calving}}{\text{Average calving interval}}$$

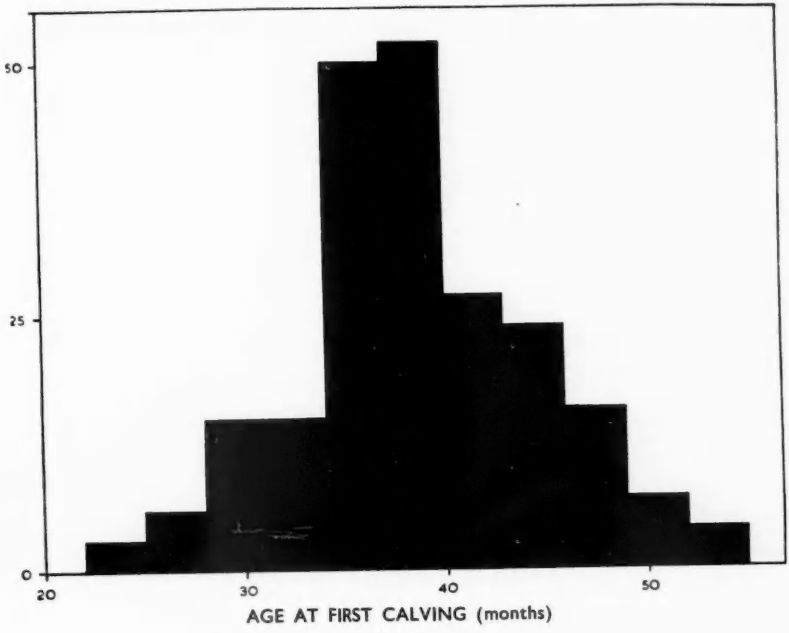
which for this population works out at 3·78 calvings, compared with the English value of 3·1. It would seem that the length of productive life in lactations (probably, by comparison with the English figures, just over 4½) is not responsible for the high age at calving, but that this is due mainly to the long calving interval.

It will be realized from this study that the primary problems that need to be tackled in regard to the Egyptian buffalo are those of management



DISTRIBUTION OF AGE OF FEMALES AT CALVING (years)

FIG. 4



AGE AT FIRST CALVING (months)

FIG. 5

and husbandry. It is therefore intended to set up experiments to study the possibility of earlier first service and its effect on first-lactation yield and also to attempt to reduce the unnecessarily long calving interval and dry period. By this means, it should be possible to increase the proportion of the animal's life in which she is producing milk.

Summary.—1. An analysis has been made of the life and calving statistics of three herds of Egyptian buffalo.

2. The average calving interval is 595 days with a lactation period of 362 days and a dry period of 231 days.

3. The average age of cows at calving is 7·7 years and at first calving is 3·2 years. The high figure for the former is not due to an unusually high productive life in lactations but rather to the long calving interval.

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THE EXPANSION OF A BREED OF DAIRY CATTLE

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IN the period between the two wars, most breeds of dairy cattle remained fairly constant in numbers, but in the middle thirties, as farming conditions improved, there began a gradual expansion of the numbers of pedigree dairy cattle, notably the Friesians and Ayrshires. This was not a general expansion of the dairy-cattle population of the country, which has increased little in number from 1935 until the present, but a replacement of non-pedigree cattle by pedigree and of one breed by another. The expansion of the Friesian breed gathered pace rapidly, and in 1947 almost four times as many pedigree heifer calves were registered as in 1935. The process was complicated by the existence of a grading-up system in which heifers were accepted for registration in the full herd-book although their dams were not. A discussion of the genetic effects of the system has already been presented in an earlier paper [1]. The present study, in its origin concerned with the importance of the grading-up system in the expansion, deals mainly with the process of expansion of the pure breed itself.

Importance of the Grading-up System

The grading-up process in the Friesian breed is in four stages. Cows are entered by inspection in the A register and after four top-crosses of pedigree bulls, the female offspring of D-grade cows may be registered in the full herd-book. In considering the effect of the system on the breed-size, we must estimate the probable size of the breed if the grading-up scheme had not existed, or, conversely, the number of females that owe their existence to the grading-up system. In cattle where the males are in biological excess the expansion is limited by the number of cows rather than of bulls. Although a heifer may trace back through her sire to a D-grade cow, it cannot be said that, if there had not been grading-up, she or her equivalent would not have existed. Her sire would merely have been replaced by another bull.

As the grading-up system was started in 1921, a direct measurement of the number of heifers in the full herd-book tracing back in the female line to a D-grade cow would be laborious even by sampling methods. It is possible to obtain an indirect estimate on the assumption that D-class cows and their descendants produce registered offspring to the same extent as their pure-bred contemporaries. Taking a given year, say 1947, we find that 3,245 pure-bred heifers were registered whose dams were registered in 1943. But in 1943 there were registered in the full herd-book and the D-grade 12,855 females whose heifer progeny could be registered in the full herd-book. We can then say that, on the average, each such female produced $3{,}245/12{,}855 = 0{\cdot}252$ registered heifer calves in 1947. In 1943, 576 heifers were registered in the

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D-class, and if these were bred from to the same extent as the pure-bred heifers, we would expect them to produce $576 \times 0{\cdot}252 = 145$ registered heifers in 1947. Summing this figure over all ages of dams, we can estimate the total number of females registered in 1947 out of D-class cows as 922. Calling this the E class, we can go a step farther and use the E figures to calculate the numbers in the F class—heifers with

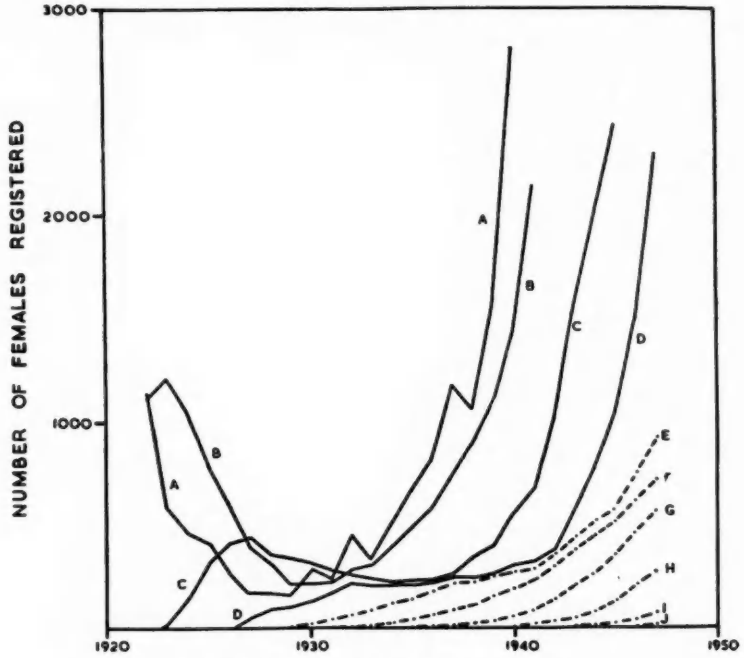

FIG. 1. Number of females in the grades.

D-class maternal grand-dams—and so on. Adding together the estimated numbers in the E and subsequent classes, we get an estimate of the total number of registered heifers born in any year which would not have existed had there been no grading-up system. This number is almost certainly a slight over-estimate, as we shall see later. The results are shown graphically in Figs. 1 and 2. Fig. 1 gives the numbers in the different grades, those in the E and subsequent grades having been calculated by the method explained above. The decline in the A and B grades after the high initial registrations is clearly shown, as well as the subsequent rise in A-grade registrations beginning about 1934. The other grades increase slowly and then more rapidly, the rapid increase in each occurring from 2 to 3 years after the same phenomenon in the preceding grade. In the D-grade many of the fluctuations in the earlier grades are evened out, and the later grades are even more regular,

although this is to some extent a result of the method of calculation. Fig. 2 shows the changes in the number of females registered in the full herd-book in each year over its entire history. A rough estimate of the total number of cows in milk at any time can be obtained by multiplying the heifer registrations by about 2·5. The hatched portion below the full curve is the estimate of the number of heifers deriving from the grading-up system and, of course, the lower curve is the estimate of expansion

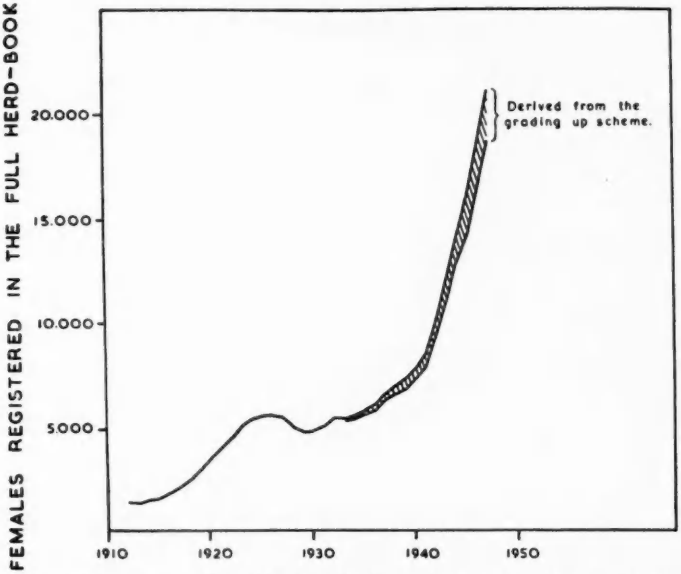

FIG. 2. The expansion of the breed; the shaded portion shows animals deriving in the female line from the grading-up system.

of the pure breed itself. Of the 21,349 heifers registered in 1947, it is estimated that only 2,572 or about 12 per cent. derived from the grading-up system. Only 8 per cent. of the pedigree cows milking in 1947, the dams of the above heifers, derived from the grading-up scheme. In a previous paper, these estimates of the numbers in the E and subsequent grades were used to show that in 1947 only about 0·4 per cent. of the genes in the registered heifers derived from A-grade non-pedigree cows. The part played by the grading-up system has not been very large in terms of its contribution to the expansion of the breed.

As the herds for which the grading-up system has been used will be rather on the fringe of the breed, it might be expected that a heifer in the grading-up register would produce fewer registered offspring than her pure-bred contemporaries. The breeder who has only got part-way in the grading-up scheme will decide more readily that he cannot afford to register his heifers, when economic conditions become worse, than will the owner of a pure-bred herd. Grading-up cows with smaller

pedigree value are also more likely to be sold to non-pedigree herds. The effect of an agricultural slump is well illustrated in the early twenties when the registrations in the A and B grades declined very rapidly (Fig. 1). It is possible to calculate the registered reproductive rate of grade animals relative to their pure-bred contemporaries, for example for the C-grade cows, by using the method described above to calculate the expected number of registrations in the D-grade and comparing it with the actual registrations. No estimate is possible for the A-grade because cows may be entered in it at any age. Table 1 shows the relative registered reproductive rates of B- and C-grade heifers in three periods.

TABLE 1. *Reproductive Rates of Grade Heifers compared with Pure-bred Contemporaries*

Period	*Grade of heifers*	
	B	*C*
1930–5	0·60	0·63
1936–41	0·75	0·82
1942–7	0·91	0·89

In the first period, which includes part of the slump years of the early thirties, only 60 per cent. of the number of offspring expected on the basis of the reproductive rate of the pure-bred heifers were registered from B- and C-grade animals. This figure rises to around 90 per cent. for the period of rapid expansion. It is difficult to obtain an accurate figure for the D-class heifers as it is a matter of estimating by sampling a fairly small percentage. In the first of the above periods, the number of offspring of D-class cows is too small for a reasonable estimate to be made. In the second and third periods we obtained, by sampling, estimates of the relative reproductive rates of 0·84 and 0·92 respectively. The estimates made above of the probable number of heifers deriving from the grading-up system, on the assumption of equal registered fecundity of D-class and full-pedigree heifers, are therefore probably too high by about 10 per cent., which, however, will not vitiate the conclusions drawn.

Mechanism of Breed Expansion

In the process of the replacement of one generation by the next, the main factor governing the change in population-size is the number of offspring produced by each individual in its life. We may take any point of the generation cycle as the starting-point, but it is necessary to count the offspring at exactly the same point in the cycle as we counted the parents. In dairy cattle we are concerned only with females, and the obvious points in the life of a cow are birth, registration, first calving, and death. In this work the main counting-point is obviously the registration of the heifer calf, but in discussion of the problem it is often more convenient to take birth or first calving as the reference point. We can then speak of the total reproductive rate, the average number of registered

heifer calves produced by each of a group of heifers, themselves counted at registration. In a breed stationary in number, this must be equal to one. If it is greater than one, the breed expands and vice versa, and the relative rate of expansion or contraction can be calculated from it.

For our purpose it is useful to split the total reproductive rate into two major components. Starting the generation cycle with a birth, we can consider the chance of that birth leading to any further births at all. In practical terms, that would be the proportion of births that produce a *heifer* that survives and is fertile. We shall call this first component the rearing proportion. It can be further broken down into sex, registration, survival in a pedigree herd, and fertility, but we shall not make such an analysis in detail. If we start the cycle at registration, the rearing proportion can be stated as the proportion of registered heifers that survive to produce a registered *heifer* at first calving, and the further analysis would comprise the survival from registration and fertility of the parental generation and the sex, survival to registration, and registration of the progeny generation. The same components are present but they are taken in a different order.

As the second component of practical interest, we have the number of births produced by animals that have any parturitions at all: the reproductive life in terms of calvings or, roughly, the average milking-life in lactations. The use of the term 'milking-life' must here be defined a little more precisely. For pedigree cows, there are three possible measures of milking-life, in order of magnitude, the average number of lactations in (*a*) the herd in which the heifer calved for the first time, (*b*) pedigree herds, (*c*) any herd. We are using it in the second sense, and it will be slightly shorter than the average total productive life.

The total reproductive rate is the product of the rearing proportion and the reproductive life. For a population stationary in size, in which the total reproductive rate is unity, the rearing proportion is the reciprocal of the average reproductive life, and is also equal to the proportion of lactations that are made by heifers. If the population size is changing, these relations are no longer true. In the calculations of the effect of the grading-up system in the expansion we estimated the partial reproductive rate, r_{ab}, as the fraction of heifers registered in year a which produce a registered heifer-calf in year b. The total reproductive rate of heifers registered in year a, $\sum_b r_{ab}$, has the practical disadvantage that it can only be measured after the last member of the group has died. Although the sum of the partial rates made in a given year, $\sum_a r_{ab}$, has no biological meaning, it is measurable instantaneously and is equal to the total reproductive rate, if the latter is constant over a period.

The estimation of rearing proportion presents some difficulty, as it is only possible to tell from the herd-books the age of the dam and not the parity of the birth. The first calvings of heifers may fall in the second, third, or fourth calendar year after the year of birth. The total number of calvings by a group of contemporary heifers in any year will depend on the distribution of ages at calving in the different lactations and on the wastage-rate from lactation to lactation. The distribution of the age

at first calving in Friesians is known [2], and from this and a knowledge of the calving interval the distribution of age at second calving can be calculated. It was estimated from these that the number of calvings of cows in the third calendar year after their birth is approximately 0·82 of the total number of first calvings from these cows. The effect of possible variations in the assumptions made is not great. It was assumed that wastage from first to second calving was 10 per cent., but this can vary widely without much affecting the above figure. Now the partial reproductive rate in the third calendar year after birth is based on the number of calvings in that year that lead to the registration of a female. If we divide that partial rate by 0·82, we get the proportion of heifers registered in a given year that produced a registered heifer-calf at first calving, which is the rearing proportion that we require.

Samples of 1,000 females were drawn at random from each of the herd-books from 1930 to 1947, and the year of birth of the dam was tabulated. The partial reproductive rates were then calculated as described above. Fig. 3 shows the sums of the partial rates $\sum_a r_{ab}$ for the different years and also the total rates $\sum_b r_{ab}$ for heifers born in years up to 1933. Some heifers born in 1934 were still alive in 1947. In the period of stability of numbers, the total reproductive rate was about unity. The sum of the partial rates in different years rises slowly until it becomes close to two in 1946 and 1947. There seems little doubt that the total reproductive rate for animals born in the early forties will be in the neighbourhood of two and may exceed it slightly. In practical terms, in the early thirties a pedigree cow, on the average, produced in her lifetime one pedigree heifer-calf that came into milk, whereas cows born in the early forties will probably produce about two heifers in milk.

We can split this increase in total reproductive rate into its two major components. The rearing proportion, estimated as described above, is shown in Table 2 as the average of periods of six years.

TABLE 2. *Rearing Proportions in Different Periods*

Year of birth of heifers	1927–32	1933–8	1939–44
Rearing proportion	0·260	0·295	0·374

In the first period, of stable population-size and total reproductive rate just over unity, the rearing proportion is 0·260 giving an average reproductive life of about four calvings. In the last period, the rearing proportion has risen to 0·374, and if we assume that the total reproductive rate for cows born in those years is likely to be around two, we have an estimate of their probable total reproductive life of 5·35 calvings. A further direct confirmation of this increase in expectation of milking-life

TABLE 3. *First Calvers surviving to Seven Years Old*

Year of birth	1929–31	1932–4	1935–7	1938–40
Proportion surviving	0·396	0·427	0·568	0·650

is found from the proportion of first-calving heifers that survive to calve in their seventh year (i.e. roughly to have a fifth lactation).

The first figure for the period of constant size agrees with the figure of 0·359 obtained from the distribution of lactations in a sample of recorded herds (presumably a population in which the age-distribution corresponds roughly to that of a population of constant size) published in the National Milk Records Annual Report for 1948 [3].

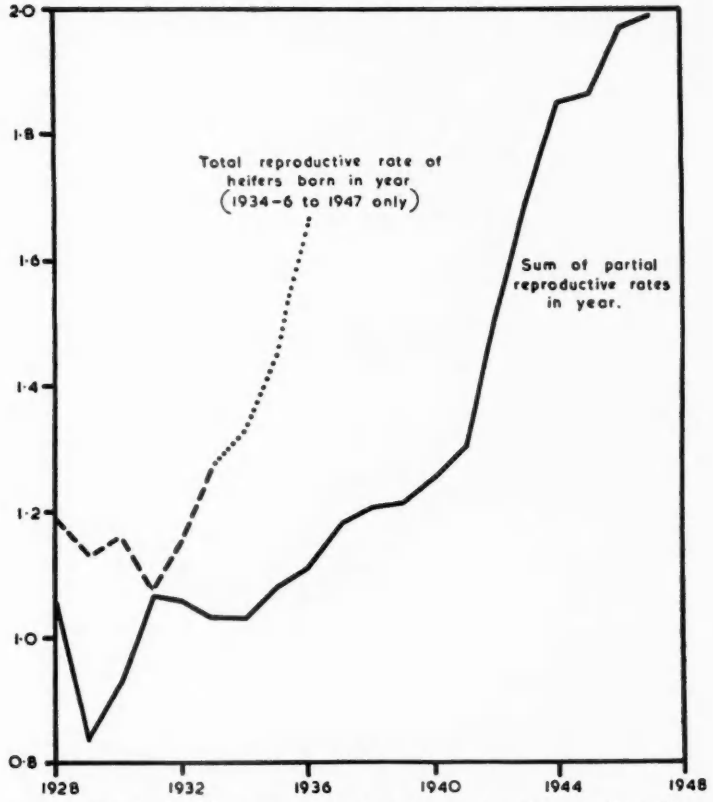

FIG. 3. The broken line – – – gives the total reproductive rates for heifers born in a given year; the continuous line —— the sum of the partial reproductive rates in a given year.

The effect of the expansion on the age-distribution of milking cows is to give at first a higher proportion of animals in the lower age-groups, as the rearing proportion is the first to react to the changed conditions. This effect continues throughout the expansion, even though the rearing proportion reaches a constant value, as the younger animals are always drawn from a larger population than the older. In the present

case the resultant decrease in average age is to some extent balanced by the increase in reproductive life. Fig. 4 gives the trend of average age at calving during the expansion. The first effect of the expansion is a slight decline of about 0·2 years followed by a gradual rise to slightly above the original figure of 5·1 years. It should be noted that the change in expectation of productive life is in no way reflected in the average age at calving: the effect of the expansion in numbers has almost exactly balanced the increase in longevity.

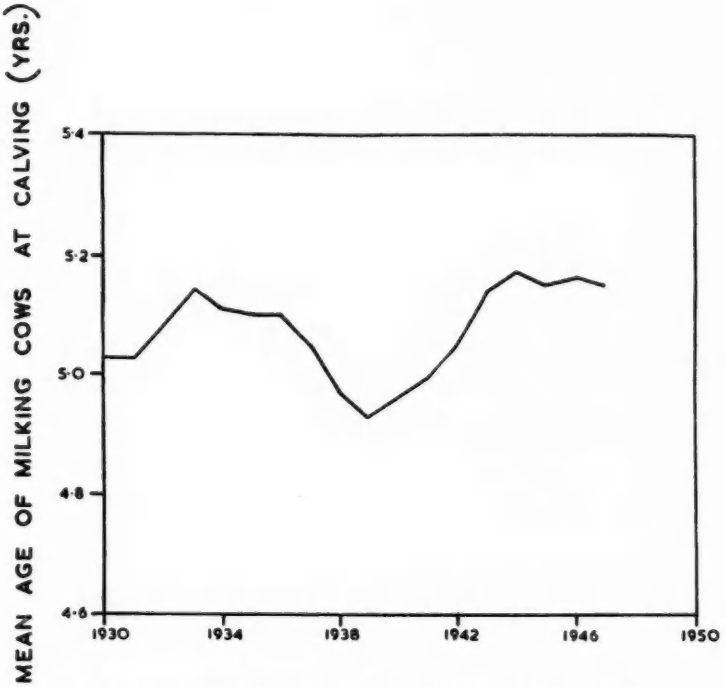

FIG. 4. Average age of cows at calving during the expansion.

To some, it may seem unreal that in the period of constant size, with an average age at first calving of 2·8 years and a milking-life of four lactations, the average age at calving is only 5·1 years. Assuming a calving-interval of 1·1 years, this means an average age in times calved of

$$1+\frac{5\cdot1-2\cdot8}{1\cdot1}=3\cdot1 \text{ calvings.}$$

Consider, however, a theoretical population with the same age at first-calving and the same productive life in which all cows have four calvings and then die at the end of the fourth lactation. The average age in times

calved is then 2·5 with an average age at calving of 4·5 years, even lower than the actual sample with the same milking-life.

Discussion

Fisher [4] has discussed the theoretical problems relating to the expansion of a population. He uses 'expectation of offspring' in the sense that reproductive rate is used here. If r_t is the reproductive rate at age t, then the expected number of offspring produced in an interval dt is $r_t\,dt$. In a dairy-cattle population we are, of course, concerned only with female offspring. If the reproductive rates at different ages do not vary with time, he shows that the relative age-structure of the population becomes stable and the population-number changes exponentially. In particular, if m is the parameter governing the exponential increase (the relative change in size in a unit of time) then the value of m is given by the solution of the equation

$$\int_0^\infty e^{-mt} r_t\,dt = 1.$$

If $\int_0^\infty r_t\,dt = 1$, then $m = 0$. That is to say, if the total reproductive rate is unity, then the population is constant in size. For the partial reproductive rates measured in the Friesian breed in 1947 with time measured in years, the solution for m is 0·127. If those rates did not change, the population would increase in number at 12·7 per cent. every year and would double in size every 5·4 years. In order to evaluate the effect of change in other variables, a model population was considered with the same relative wastage for all lactations, with age at first calving a years, calving interval c years, reproductive life L, and total reproductive rate R. An approximate solution for m is then

$$m = \frac{R-1}{(L-1)c+aR}$$

and the generation interval in the female line is $a+(L-1)c$. As in practice the wastage-rate increases with age, the expression gives rather too small a value in the present case.

Earlier we analysed the rearing proportion into sex-ratio, registration, survival in a pedigree herd, and fertility of the heifer. Of these, the sex-ratio and the fertility of heifers will be affected little by changes in management policy. The increase in the rearing proportion from about 0·26 in the periods of constant population-size to about 0·37 in the period of rapid expansion is probably due to changes in the other two factors, registration and survival in a pedigree herd. It is difficult to obtain evidence on this point, but it seems likely that the important factor would be the sale of heifers to non-pedigree herds. In a period of constant population-size, more pedigree heifer calves are born than are needed to provide replacements and the surplus are sold to non-pedigree herds. In the expansion almost all the heifers will probably stay in pedigree herds. There are no figures available for the number

of fertile heifers that can be reared from 100 births, but it is possible to make an indirect estimate by the use of some data from New Zealand [5]. Taking as a starting-point 100 cows about to calve and a secondary sex-ratio of 0·48, it would be expected that of these 48 heifers 10 per cent. will be lost through abortions, stillbirths, and deaths up to 6 months, 5 per cent. by deaths up to first calving, and a further 5 per cent. will not be fertile. This would leave about 38 heifers in calf, in reasonable agreement with the figure of 0·374 for the rearing proportion in the Friesian breed in the period of expansion.

In addition to the increase in the rearing proportion the average number of calvings per cow has also increased from around four to about 5·4. In a previous paper on the longevity of the dairy cow [6] it was emphasized that the consideration of the average milking-life of cows as a measure of the general vigour of the breed is unjustified. In many quarters the idea has prevailed that the average milking-life of cows is at present very low (which in the above study was shown to be based on an incorrect interpretation of the data), and that this was possibly due to a decline in vigour arising from high yield. In this present study we have seen that the average length of productive life depends considerably on economic circumstance. Since it has become profitable to rear and sell pedigree heifers, the average number of calvings per cow has increased. In a population of constant size the exact balance between rearing proportion and productive life which will make the total reproductive rate equal to one is rather arbitrary and the observed average productive life may have little reference to the vigour of the breed. For instance, one often assumes that the wastage-rate controls the replacement rate; that a heifer comes into the herd because an old cow goes out. It must often be true, however, that due to limited accommodation an old cow has to be sold because there is, say, a heifer out of a good dam about to calve. The point of balance between the rearing proportion and the productive life to keep the population constant can vary within wide limits from a productive life of less than three calvings to over five. There is a fair amount of evidence from this and other studies that in this country the balance-point occurs with a rearing proportion of 0·25 and a productive life of four lactations [6, 7, 8]. It would certainly be unwise to attach too much biological significance to that value for productive life.

In such a state, a dairy breed has considerable unused fecundity which will allow it, when necessary, to expand very rapidly. By increasing both the proportion of heifer calves reared and kept in pedigree herds and the average productive life, the excess fecundity in the Friesian breed is such that each heifer can leave about two replacements for herself and that the breed can double in size every $5\frac{1}{2}$ years.

Summary

1. The Friesian breed increased almost fourfold in size from 1935 to 1947. The grading-up system played only a small part in the expansion and not more than 12 per cent. of the heifer-calves registered in 1947 owe their existence to it.

2. The main factor governing such an expansion is the total reproductive rate (the number of heifers that come into milk, produced by a cow in her lifetime). This was close to unity in the period of stationary numbers but has probably increased to around two for heifers born in the early forties. At the present reproductive rates, it is estimated that the pure breed would double in size every $5\frac{1}{2}$ years.

3. The total reproductive rate has been analysed into the rearing proportion (the proportion of births that give a heifer in milk in a pedigree herd) and the reproductive life (the average number of calvings of heifers that come into the herd). In the period of constant size, the rearing proportion was 0·26 and the reproductive life around four lactations. In the period of rapid expansion the rearing proportion increased to 0·37 and the reproductive life to about 5·4 calvings.

4. It is emphasized that a dairy breed at constant size has a considerable reserve of fecundity, and it is most unwise to attach too much biological significance to the average productive life in such circumstances.

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A SURVEY OF PIG-HOUSING

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IN a previous communication the authors [1] emphasized the lack of data regarding fundamental requirements for optimum environmental conditions in pig-houses. Whilst it was realized that controlled experimental conditions would be necessary in order to collect exact information as to the requirements for health and productivity, it was felt that some useful general information might be obtained by making a detailed survey by modern scientific methods of the environmental conditions in a number of commercial piggeries, and correlating the results with the state of health of the animals contained therein. It was appreciated that nutritional and genetic factors would play some part in the variations observed as, of course, would also specific disease conditions, but it was felt that even in such a general survey sufficient allowance could be made for these variables to allow of classification of the buildings into 'good' and 'bad' types so far as their effects on general health and productivity were concerned. That this conception was not altogether invalid is shown by the facility with which, on a number of occasions, buildings could be transferred from the one category to the other simply by modification of housing conditions with no alteration in animals, feeding, or any other factor.

Piggeries Surveyed

Piggeries were examined on six farms (A to F) in the vicinity of Edinburgh and on three near Aberdeen (G, H, and I). On all the farms near Edinburgh complete records were made; however, at two of the Aberdeenshire piggeries opportunity was available for only limited observations.

Farm A. The only piggery there (A_1) was the usual type of brick building with a concrete floor, and pens on each side of a central feeding-passage. Here litters and young stores were unthrifty in winter and the winter fattening-rates had been found to be poor compared with the summer results.

Farm B had five different types of piggery:

B_1. A Nissen hut was divided into pens having concrete floors with brick sleeping-beds. Newly-weaned pigs were being kept; in winter they did badly, and at the time of the survey they looked unthrifty; there was excessive growth of hair, corynebacterial abscesses were present on a number of the pigs, and huddling was much in evidence.

B_2. A farrowing-house, built partly of brick, partly of stone and lime; here again the winter results were poor and litters tended to huddle and appeared unthrifty.

B_3. A converted cowshed with walls of stone and lime, used to accommodate litters and young stores; again in winter time the young pigs looked unthrifty and miserable.

[Empire Journ. of Exper. Agric., Vol. 19, No. 75, 1951.]

B_4. A brick fattening-house having a central feeding-passage with pens on each side and a wide opening along the ridge of the roof. However, the sleeping-quarters were well sheltered by the solid brick partition walls of the pens and low brick walls surrounding the actual sleeping-beds; here the fattening-pigs appeared to be thriving.

B_5. A brick piggery provided with open runs; there was a wide, open doorway between each run and the inside compartment; sows and boars seemed to be living quite successfully in this type of accommodation.

Farm C. Five piggeries were surveyed:

C_1 was a farrowing-house of large dimensions, with walls built partly of brick and partly of wood and having the Danish type of layout. The winter results in this piggery had been very unsatisfactory; but following the installation of electric radiators over the nests quite good results were achieved.

C_2 was a large fattening-house, built partly of brick and partly of wood; the dimensions were relatively large and straw-covered shelters enclosed on three sides were built within the pens. Here fattening pigs appeared to be thriving.

C_3 was a similar type of fattening-house but the south side of the building was open; the results in this piggery during cold winter weather were unsatisfactory, large fattening-pigs having gained only about 3 lb. weekly in spite of normal feeding.

C_4 was a brick piggery with open runs; the sleeping-compartment had relatively small dimensions. The results with fattening-pigs were reasonably satisfactory.

C_5 was a somewhat poorly constructed pig-ark with openings at front and rear, the walls being of $\frac{1}{2}$ in.-boarding with no special insulation. This hut had been found unsuitable for the winter rearing of pigs.

On *Farm D* three piggeries were surveyed:

$D_{1(a)}$ and $D_{1(b)}$ were two wings of a substantially built farrowing-house of very large dimensions. The winter-rearing results here were unsatisfactory until ventilation was restricted, straw-covered shelters built in the pens, and artificial heating provided. Following these measures results were reasonably satisfactory.

D_2. A large piggery of the Danish type. Fattening-pigs in this house were doing reasonably well.

D_3 was a pig-ark with walls of $\frac{3}{4}$ in. wood. It was not very tightly built and there were doors and ventilators both at the front and back. Winter results in this hut were unsatisfactory.

Farm E had five types of piggery:

E_1 was a farrowing-house, built of stone and lime, having large dimensions and free ventilation; the winter results here were ruinously bad, whole litters often dying and a 50 per cent. death-rate being very common. When artificial heating was installed in the floors at the back of the pens and also hot-pipes along the back-walls of the pens and the ventilation restricted, the rearing results became satisfactory.

E_2 was a brick shelter with a wooden roof erected within a high airy piggery; the results with newly weaned pigs in this shelter were very satisfactory.

E_3 was a fattening-house consisting of a straw-covered shelter enclosed on three sides within a large draughty building; the fattening-pigs were said to be making satisfactory gains in this house.

E_4 was a straw-covered shelter enclosed all round except for a small doorway, placed in a large draughty piggery; here newly weaned pigs were thriving normally.

E_5 was a well-constructed pig-ark with double walls and an insulating lining, in which air-flow was carefully controlled. Here again the winter results were entirely satisfactory.

On *Farm F* there was one piggery which was surveyed, then altered and surveyed again:

F_1 was the piggery in its original state, viz. an incompletely covered straw shelter with free ventilation within a large airy building. Litters of newly weaned pigs were doing badly, both anaemia and necrotic enteritis having been diagnosed.

F_2 was the same piggery after the straw roof had been thickened and made to cover the pen completely and the ventilation further restricted by putting a sack over the entrance; under these conditions young pigs remained healthy.

Farm G.

G_1, G_2, and G_3 were experimental piggeries at a large Research Institute. G_1 was a farrowing-pen in a large airy stone building; here the results were bad, the piglets developing anaemia in spite of adequate diet.

G_2 was an ark rather freely ventilated, having its walls partially insulated; it communicated with a run inside the same building where G_1 was situated; here the piglets were not thriving satisfactorily although doing somewhat better than in G_1.

G_3 was a tightly built ark with partly insulated walls and an outdoor run; here the piglets were thriving exceptionally well.

On *Farm H* there were two types of piggery:

H_1 was a large type of Danish piggery with a false roof of straw bales; the results here with fattening-pigs were satisfactory.

H_2 comprised substantially built, partially insulated arks with restricted ventilation; litters were reared quite successfully in these arks even in winter.

On *Farm I* there were shelters or kennels with restricted ventilation built within a large airy Danish piggery; the results were satisfactory. By this means an almost useless pig-house had been modified to allow of reasonable rearing results.

Methods.—Measurements were made of air-temperatures, floor-, wall-, and roof-temperatures, mean radiant temperatures, relative humidity, rate of air-change, and the daylight factor. To elucidate the position further with regard to the factors that were affecting temperatures, humidities, &c., measurements were made of floor-space, cubic space, area, and position of inlets and outlets, doors, and windows. Particular attention was also paid to the structure of the building, the nature of floors, walls, roofs, &c., the amount of trough-space, the cleanliness and the subjective impression given by the piggery.

Air-temperatures were measured usually over a period of a week or longer by means of recording thermographs which were periodically calibrated against mercury thermometers; mercury thermometers were also used for check-readings; mean radiant temperatures were measured by means of a globe-thermometer. For floor-, wall-, and roof-temperatures a thermocouple connected to a galvanometer was used. Effective temperature was calculated by the method of Houghten and Yagloglou [2]. Relative humidity was recorded by means of hair hygrometers calibrated against the sling hygrometer. Rate of air-flow was measured by means of a pitot tube, a silvered Kata thermometer, or a velometer, depending on the size of opening involved and the rate of air-flow; the

direction of air-flow was ascertained by using a simple smoke-generator. The daylight factor as internationally defined was obtained by measuring the light inside and outside the buildings by means of a photo-electric photometer, using the standard method. Heat losses from buildings were calculated from the temperature difference between outside and in, the air-change per hour, and the area, thickness, and nature of walls, roofs, and floors.

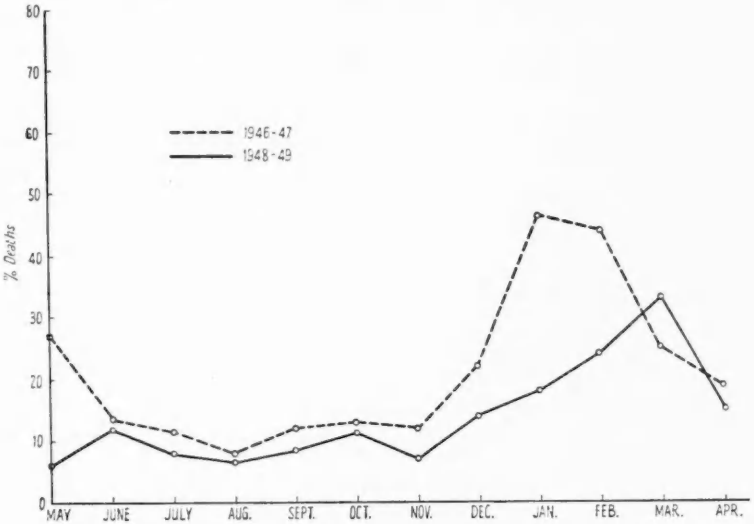

FIG. 1. Deaths each month expressed as percentage of most susceptible population, i.e. of pigs born during that and the previous month.

In order to simplify the comparison of data, the total number of pigs present in a building was converted to the number of 200-lb. pigs which would have the same heat-output, utilizing the experimental data on heat production quoted by Mitchell and Kelley [3]; cubic space, air-supplies, &c., for the building were divided by this number to obtain the cubic space, air-supply, &c., per 200-lb. pig equivalent.

Results

General health.—Even under what were considered fairly good conditions, viz. $D_{1(a) \text{ and } (b)}$ after modification, the death-rates in piglets were highest in the winter and early spring months as is shown in Fig. 1. Here the deaths are expressed as a percentage of the most susceptible population, i.e. of the pigs born during a particular month and the previous month, as it was found that the vast majority of the deaths took place in this group. It will be noted also (Fig. 1) that the death-rate was much higher in the winter of 1946–7 than in the winter of 1948–9; the former was much colder than the latter. Under what were classified as bad

conditions encountered in the survey, although accurate figures were not always obtainable, there were histories of the rearing-results in winter being often quite disastrous, as in E_1. In young pigs kept under conditions where the temperature tended to be abnormally low in cold weather various conditions were encountered. Pigs often had a thin, unthrifty appearance with excessive growth of hair and poor live-weight gains; in extreme cases this type of pig died and post-mortem examination often revealed anaemia or occasionally necrotic enteritis. A humped-back condition in piglets was frequently encountered and huddling was common. Corynebacterial abscesses were prevalent in one herd.

In older pigs such as large stores and fatteners, although there was no evidence of frank ill health, there were histories of poor live-weight gains, in spite of normal feeding, in certain types of piggeries during cold weather. In one case large fattening-pigs gained only 3 lb. weekly and in another case the live-weight increases were negligible. Adult sows and boars on the other hand appeared to be quite successful even during cold weather when kept in houses where the temperatures differed little from outside.

Air-temperature.—In Table 1 are set out the temperature conditions in a number of piggeries together with the outside temperature over periods of a week. In each of these piggeries a litter, litters, or young stores were being reared. Piggeries G_1, G_2, and G_3 are of especial interest as measurements were made simultaneously and litters were under identical feeding conditions and of approximately the same age and size.

TABLE 1. *Temperatures inside and outside Piggeries**

Piggery	*Average air-temp.*	*Minimum air-temp.*	*Maximum air-temp.*	*Average outside temp.*
G_1	50·5	46	64	46·8
G_2	55	46	64	46·8
G_3	60	51	70	46·8
A_1	45·5	39·5	50	38
B_1	37·9	30	45	34·2
$D_{1(a)}$	51·75	49·5	55	35·4
$D_{1(b)}$	51·92	49	55	38·2

* All temperatures in this paper are given in degrees Fahrenheit.

Pigs in G_1 were typical bad doers, abnormally hairy, with a poor, unthrifty appearance; they averaged 10 lb. at 3 weeks and 15 lb. at 6 weeks, and one died at 8 weeks. The litter in G_2 did not appear to be thriving well, the average weight was 12 lb. at 3 weeks and 23·5 lb. at 6 weeks. In G_3 the litter of pigs was thriving and weighed on the average 14·5 lb. at 3 weeks and 27·5 lb. at 6 weeks. In piggeries A_1 and B_1 young stores were doing badly, whilst in $D_{1(a)}$ and $D_{1(b)}$ young litters were doing satisfactorily. It will be noted that in piggeries G_1 and G_2, where the average temperatures were 50·5° and 55° respectively, the pigs were not thriving, whilst in $D_{1(a)}$ and $D_{1(b)}$ at average temperatures

of 51·75° and 51·92° the litters were doing well. This discrepancy is undoubtedly accounted for by the fact that measurements were made in G_1 and G_2 at a time when the outside temperature was not particularly low, being on the average 46·8, whilst when $D_{1(a)}$ and $D_{1(b)}$ were being investigated the average outside temperatures were 35·4° and 38·2° respectively. There is no doubt that the temperatures in piggeries G_1 and G_2 fell much lower in colder weather. If we take as our criterion of temperature the difference between outside and inside, we find that in piggeries G_1 and G_2, where the pigs were doing badly, the figures are 3·7° and 8·2° respectively, whilst in piggeries $D_{1(a)}$ and $D_{1(b)}$ the differences are 16·3° and 13·7°. It would thus appear that, although the absolute temperature of a piggery is doubtless of critical importance to the pig, in assessing the quality of a piggery during a survey, the difference between outside and in is a much more useful figure. Buildings are of necessity surveyed under different outside conditions and in all buildings without artificial heating, changes in outside temperature cause corresponding although not always equal changes in inside temperature. We therefore adopted temperature-differences between outside and in as the criterion of temperature when comparing different types of piggeries, and we felt this figure would be of special significance if it was the average obtained over a fairly long period, say, a week or a fortnight.

Surface-temperatures.—It was thought that measurements of floor-, wall-, and roof-temperatures might be of considerable interest, but on the whole they varied little from air-temperatures. Exceptions to this were places where the pigs were actually lying and on the surface of deep litter. The surface-temperature in the case of wet floors was invariably below the air-temperature and usually corresponded with the wet-bulb temperature of the atmosphere, whilst floor-temperatures where the pigs were lying tended to approach the surface-temperature of the pig; only one piggery (a section of C_3) was encountered where the pigs were trampling straw to make farmyard manure, and in this case the temperature of the bed was about 9° higher than the atmospheric temperature. Floor-, wall-, and roof-temperatures in the piggeries surveyed would consequently appear in themselves to tell us little more than air-temperatures. However, the fact that the floor-temperature under the recumbent pig approaches that of the surface of the animal suggests that heat conduction through a floor may be of very considerable importance. This heat-flow from the pig will obviously vary with the temperature and nature of the floor and the temperature under the floor. Unfortunately, no satisfactory method for measuring this loss is at present available.

Globe-temperature.—It has been suggested that the globe-temperature, which not only measures air-temperature but also radiation effects, might be of special value in assessing the quality of a piggery. However, it was found to have no practical advantage over the air-temperature under the conditions of the survey. The globe-temperature was usually within ±1° of the air-temperature and, when average temperatures were being considered, appeared to offer little or no useful information additional to that obtained from the air-temperature differences.

Effective temperature.—Effective temperatures were also estimated for the buildings surveyed as it was felt that, since in addition to taking into consideration air-temperature, they also allowed for air-movement, they might provide a better criterion than the air-temperature. It was, however, not found possible to make continuous records of air-flow, data on effective temperatures were necessarily very limited and difficult to compare. Their value in this type of field survey is, therefore, limited.

Breeding- and Rearing-Houses

In Tables 2 to 5 are recorded findings in a series of piggeries used for housing litters and young stores.

Table 2 A includes those buildings where the young pigs were thriving reasonably well and in all except F_2 the pigs had access to an outside run. The great variation in air-supply per hour per 200-lb. pig shown in the table is of especial interest in view of our lack of accurate knowledge of essential requirements; it will be noted that the supply per hour varied from 239 to 2,226 cu. ft., although the pigs receiving only 239 cu. ft. per hour had free access to the outside. However, there was no doubt the pigs remained for relatively long periods at a stretch, e.g. from night till morning, inside the shelter, and the pigs in F_2 to which air was supplied at the rate of 397 cu. ft. per hour had no access to any other accommodation. Table 2 B sets out corresponding data for breeding- and rearing-houses where pigs were thriving badly or where the death-rate was high during the cold seasons. In these piggeries the air-supply varied from 787 to 43,778 cu. ft. per hour per 200-lb. pig and was on the average about six times as great as in the piggeries referred to in Table 2 A. There is no doubt that these air-supplies were far beyond the needs of the pigs and were, of course, having a depressing effect on the temperature conditions, particularly in winter. Cubic space, floor-space, and surface-area per 200-lb. pig varied widely in both groups, and in group B were obviously needlessly high.

In respect of temperature-differences between outside and in, it will be seen that in the first group this figure varied from 9·7° to 17·2° with a mean of 13·3°, and the second group from 2° to 8·7° with a mean of 5·9°. The means were found to be significantly different when examined statistically. As already indicated, when the temperatures of piggeries E_1, D_1, and C_1 were raised by various methods they became quite satisfactory for rearing purposes. In piggery E_1 during the winter, by means of warm pipes in the floor towards the back of the farrowing-pens and along the back-wall at a height of 2 ft. 9 in., the temperature of part of each pen protected by a canopy was raised to an average of 78·9°; and the general atmospheric temperature in the piggery was brought to 53·1°. Under these conditions the rearing losses became very small indeed, being only about 3 per cent., and the litters gained satisfactorily in weight. When, under straw-covered shelters in piggery D_1 the temperature was raised to 51·7° and the general atmospheric temperature of the piggery to 48·5° by means of hot pipes, the pigs were in apparently

TABLE 2. *Physical Data from Piggeries*

A. PIGS THRIVING

Piggery	Mean temperature diff. between outside and in, in °F.	Cubic space per 200-lb. pig in cu. ft.	Floor space per 200-lb. pig in sq. ft.	Surface area per 200-lb. pig in sq. ft.	Air-supply per 200-lb. pig in cu. ft. per hour	Daylight factor %	Humidity % diff. between outside and in
E_5	17·2	64	27·2	83	239	Too dark to record	+27
G_3	13·2	78	18·8	78	1,696	0·36	− 3·4
E_2	13·9	19·2	4·8	17·4	2,226	Too dark to record	+25
F_2	9·7	137	34	135	397·5	0·36	Nil
E_4	12·3	17	4·3	19	2,141	Too dark to record	− 3
Mean	13·3	63·0	17·8	66·5	1,340	..	..
Standard error of mean	±1·21	±22·1	±5·9	±22·0	±427	..	..

B. PIGS NOT THRIVING

G_1	3·7	630	49·5	130·7	12,508	1·2	+2·7
G_2	8·7	48	19	52·6	5,212	0·2	−0·3
E_1	6·3	382	29	123	4,929	0·075	−2
D_1	3·2	1,780	139	390	13,409	0·14	+1
D_3	7·4	141	43	151	43,778	1·4	nil
C_5	7·5	140	23·5	84·2	4,096	1·1	−8
A_1	7·5	394	40	117	787	1·2	−6
B_3	7·2	414	33	106	1,395	0·2	+3·5
B_1	3·5	214	23	77	2,369	0·07	−2
B_2	6·5	627	101	287	2,363	0·07	+5
F_1	2	137	34	135	10,455	0·36	+1
C_1	7·7	1,096	87	267	6,160	0·03	−3
Mean	5·9	500·3	51·8	160·0	8,955	..	..
Standard error of mean	±2	±144·0	±10·8	±29·2	±3,992	..	..

thriving condition and making satisfactory gains, although the outside temperature was low. When a warm nest was provided in piggery C_1 by suspending an electric heater above it, the results became satisfactory, the average temperature under the electric radiator being 70·6°.

In view of the limited value of absolute temperatures during a survey, it is of interest to note the differences between outside and inside in piggeries E_1, D_1, and C_1 under the conditions where pigs were thriving and the death-rate low in cold weather, and when the reverse was the case. This comparison is set out in Table 3. When conditions provided a temperature difference of at least 16°, the results in cold weather became satisfactory.

TABLE 3. *Temperature Differences between Outside and In*

Piggery	*Pigs doing well*	*Pigs doing badly*
E_1	10° (in building as a whole) 35·8° (in warm shelter)	6·3°
D_1	16·3°	3·2°
C_1	27·5°	7·7°

As will be seen from Table 2, humidity variations cannot be correlated with the well-being of the pigs in the piggeries surveyed. The humidity of the various buildings surveyed appeared to vary mainly with the outside humidity and only rarely did the percentage relative humidity in any of the buildings examined differ very much from the outside. In these rare instances there was no evidence of any adverse effect on the pigs.

The daylight factor, i.e. the proportion of the outside light entering the buildings, did not seem to be of vital importance under the conditions encountered during the survey. It must, however, be borne in mind that in all cases met with in the survey where the house was excessively dark, the pigs had free access to runs which were quite light.

Analysis of heat-losses.—Since the evidence accumulated emphasizes the great importance of temperatures inside piggeries for housing young pigs and also suggests the very wide extent of unsuitable conditions, it is of interest to analyse the ways in which heat was lost. This analysis is set out in Table 4.

The heat-losses in the 'good' type of piggery were due on the average to air-flow and through the surfaces in nearly equal proportions. In the farrowing-houses E_5, G_3, and F_2, the surface-losses tended to be much larger than in piggeries E_2 and E_4, which were store accommodation; as farrowing-houses must provide a fair amount of floor-space to prevent crushing, this also increases roof and wall areas, leading to relatively high surface-losses. Air-flow losses varied fairly widely and as the pigs were doing quite well even in these piggeries with restricted air-flow, it would seem that the winter temperature conditions in the rest of the piggeries could be further improved by restricting ventilation. Only in piggery E_5 had there been any real attempt at insulating walls and floors; consequently the temperature conditions in the other piggeries, and

TABLE 4. *Heat-losses in B.T.U.s per hour per 200-lb. Pig per Degree Difference between outside and in (corrected to a wind velocity of 3 m.p.h.)*

A. GOOD PIGGERIES

Piggery	*Air-flow*	*Walls*	*Floor*	*Roof*	*All surfaces*	*Total*
E_5	4·5	11	15	..	26	30·5
G_3	32	45	9	..	54	86
E_2	42	4·5	1	2	7·5	49·5
F_2	7·5	26	3·5	9	38·5	46
E_4	40·4	5·4	0·9	1·1	7·4	47·8
Average	25·3	18·4	5·9	2·4	26·7	52·0

B. 'BAD' PIGGERIES

G_1	236	34·7	9	32·3	76	312
G_2	99	25·3	11	..	36·3	135·3
E_1	93	13·4	8·4	8·4	30·2	123·2
D_1	253	20·6	27·8	111·8	160·2	413·2
D_3	826	103	59·8	..	162·8	988·8
C_5	61·6	49·2	9·6	..	58·8	120·4
A_1	15	23·8	3·9	21·6	49·3	64·3
B_3	26	10·8	7	18	35·8	61·8
B_1	45	36·8	4·3	..	41·1	86·1
B_2	44·6	30·6	20·2	40·4	91·2	135·8
F_1	198	26·3	6·8	8·9	42	240
C_1	116	47	19	149	215	331
Average	167·8	35·1	15·6	32·5	83·2	251·0

particularly in piggeries G_3 and F_2, could have been improved by efficient insulation of floors, walls, and roof. Walls caused on the average the bulk of the heat-losses from surfaces. It must, however, be remembered that we are at present referring to heat-losses from the atmosphere; heat-losses through the floor may be of relatively greater importance when we consider direct loss from the animal, but, as pointed out earlier, there is as yet no satisfactory method of assessing this.

It will be observed that in piggeries where the pigs were not thriving the estimated heat-losses were on the average about five times as great as in those where results were satisfactory. Excessive heat-losses in the 'bad' piggeries tended to be mostly due to air-flow losses which on the average were about twice as great as surface-losses. This suggests that the main contributory factor to 'bad' piggeries in this country is excessive ventilation. It was found, moreover, that this was not usually due to orthodox ventilators but to adventitious openings produced by buildings not being soundly constructed; in addition broken window-panes and doors being left open were contributing factors in a number of instances. Both air-flow losses and surface-losses tended to be much greater in the 'bad' piggeries than in the 'good', the former being on the average about $6\frac{1}{2}$ times, the latter about 3 times as great. This means that when compared with the 'good' piggeries, the 'bad' piggeries had too much ventilation, were too large, and not adequately insulated. Although a

relatively large floor-space is desirable in a farrowing-house, in the case of $D_{1\,(a)\text{ and }(b)}$, D_3, B_2, and C_1 much more floor-space was allowed than necessary. The houses were also too high and there had been little attempt at insulating, although in two of these piggeries the roofs were lined with boarding. The heat-losses from the atmosphere inside the 'bad' piggeries through floors tended to be much smaller than those through walls and roof; however, in piggery D_3 the heat-loss through the floor was high owing to a free flow of air under the floor; the heat-loss through the floor in piggery $D_{1\,(a)\text{ and }(b)}$ was also somewhat high and this was associated with an abnormally large floor-space per sow and litter, viz. 198 sq. ft.

Fattening-Houses

In Tables 5 and 6 are recorded findings in a series of fattening-houses. Although there were no records of deaths in fattening-pigs associated with low environmental temperatures, in piggery C_3, where the temperature difference between outside and in was only 2·7°, the live-weight gains were very poor in the winter months. In another piggery, not recorded in this paper as there was no opportunity of a complete survey, where the temperature-difference between outside and in was only 1°, we were informed that live-weight gains in the winter months had been negligible in spite of normal feeding. There were no complaints with regard to the other piggeries referred to in Table 5, although in every case the temperature conditions inside in the winter months would be colder than

TABLE 5. *Observations recorded in Fattening-Houses*

Piggery	*Mean temp. diff. between outside and in* (° F.)	*Cubic space per 200-lb. pig* (*cu. ft.*)	*Floor space per 200-lb. pig* (*sq. ft.*)	*Surface area per 200-lb. pig* (*sq. ft.*)	*Air supply per 200-lb. pig in cu. ft. per hour**	*Daylight factor* %	*Humidity* % *diff. between outside and in*
C_3	2·7	415	37	90	36,304	0·26	Nil
C_2	6·3	273	21	53·3	859	0·01	+2
C_4	7	45	9·8	27·4	1,146	0·16	−5
B_4	9·5	194	27	57·5	3,412	0·13	+2
E_3	9·75	43	9	14·8	7,312	0·015	+5
D_2	12	306	22	55	1,500	0·05	+16

* Corrected to a wind velocity of 3 m.p.h.

the optimum mentioned by Hertman and Hughes [4]. Whereas the number of fattening-houses surveyed was too small to justify statistical analysis of results and all the factors listed varied greatly, it is of especial interest that the findings in C_3 were the most extreme. It will be noted that the air-supply varied enormously.

Table 6 shows that the total heat-losses also varied greatly, but again the piggery C_3 with poor winter results was the one where they were most

extreme. Heat-losses from air-flow and from surfaces both varied widely; it is obvious that without danger to the pigs and without much expense, each could be cut to the order of the lowest figure quoted, when a piggery would be obtained with very reasonable winter-temperature conditions. If that were done, it would be quite easy to reach the optimum temperatures given for fattening-houses by Hertman and Hughes [4] without resorting to artificial methods of heating.

TABLE 6. *Heat-Losses in B.T.U.s per hour per 200-lb. Pig per Degree-difference between Outside and Inside of Fattening-Houses (corrected to a wind velocity of 3 m.p.h.)*

Piggery	*Air-flow*	*Walls*	*Floor*	*Roof*	*All surfaces*	*Total*
C_3	685	8·1	7·4	67	82·5	767·5
C_2	16	8·1	4·2	31·2	43·5	59·5
C_4	21·6	4·7	2·0	13·7	20·4	42·0
B_4	64·4	4·2	4·0	29	37·2	101·6
E_3	138	5·5	1·8	0·4	7·7	135·7
D_2	29	4·5	4·5	35	44	73

Sows and Boars.—During the survey we failed to find evidence of adverse effects of housing on adult sows and boars. Under the variety of conditions already described, with their varying effects on young and fattening-pigs, the sows and boars never appeared to be upset. In Table 7 are set out the environmental conditions encountered in a typical house used for sows and a boar in which they appeared to be healthy, although the conditions did not give satisfactory results with young stock.

TABLE 7. *Conditions in a Typical House for Sows and a Boar*

Piggery B_5:

Mean temperature difference between outside and in	4·5° F.
Cubic space per 200-lb. pig	69 cu. ft.
Floor space per 200-lb. pig	14 sq. ft.
Surface area per 200-lb. pig	36·1 sq. ft.
Air-supply per 200-lb. pig per hour	427 cu. ft.
Daylight factor	0·02%
Humidity	2% higher inside

Discussion

During the survey the bad results obtained in the winter rearing of litters and young stores were amply confirmed. It is of especial interest that of 17 breeding- and rearing-houses examined 12 or 70 per cent. were classified in the group giving unsatisfactory results. But when the environmental findings in the 'good' and 'bad' houses were compared, of the data recorded only the temperature-difference between outside and in was found to be significantly different in the two groups. It was obviously the combined effect of air-flow and surfaces which was leading to the significantly lower temperature-difference between outside and inside the 'bad' piggeries.

It is also obvious that no accurate figure of difference between outside and inside temperature could be stated which would be generally suitable, because what would be sufficient in mild or moderately cold winter conditions might not suffice in very cold weather. It is, however, noteworthy that pigs were doing badly in winter when the difference between outside and in was 8·7° or less; on the other hand, when the difference between outside and in was 12·3° or higher, reasonably good results were being obtained. There is thus some evidence to indicate that under winter conditions in this country it is desirable to insulate buildings, arrange size, and adjust ventilation, or supply artificial heat to obtain a temperature-difference certainly over 9° and probably at least about 12°. If we add this difference to the average temperature encountered during the cold months of the year, i.e. about 40°, we come to the conclusion that to obtain reasonably good results in the rearing of pigs the average temperature should never drop below 50° inside the piggery. This does not, of course, imply that such a temperature is the optimum, but we found no evidence to support the necessity for temperatures as high as 70° and 80°, which are sometimes recommended.

Whilst temperature conditions were found to be of vital importance for the health of the young pig, especially in the first few weeks of its existence, they did not appear to be so for the health of the fattener, particularly in the later stages; here at most they influence the rate of gain, and, of course, severe conditions may stop live-weight increases completely in spite of normal feeding; this is well illustrated in the Auchincruive Report [5] where the average live-weight increase per pig of 7 lb. per week represented a variation from over 8 lb. per week in the summer to less than 6 lb. per week in the winter months. But real ill health appears to be less and less traceable to cold as the pig grows older, whilst adult sows and boars appear to be relatively immune to the effects of such temperature variations as are likely to occur in normal climatic conditions. However, none of the fattening-houses encountered would reach, during cold weather, the optimum temperatures stated by Hertman and Hughes [4], viz. around 75°, for pigs around 100-lb. live-weight, and about 60° for pigs of about 200 lb.; whether or not these are the optimum for pig-fattening in this country remains still to be determined.

We found little to support the claims for the large air-flow requirements of some 800–1,000 cu. ft. per hour quoted by various authors. From the figures given in Table 2 A it will be seen that an air-supply somewhat less than half that amount proved quite sufficient for a 200-lb. pig, and there is reason to believe that even lower figures might be satisfactory. This greatly eases the task of providing reasonable temperature conditions during cold weather. It is obvious, too, from the same table that the space-allowance sometimes quoted of some 300–400 cu. ft. for a sow is unnecessarily large and that particularly in pens with outside runs a cubic capacity of the order of 60 cu. ft. per 200-lb. pig was sufficient; in terms of the average sow and litter this would work out at about 150 cu. ft. Some satisfactory farrowing-houses were encountered having a cubic capacity of this order with a floor-space of 50–60 sq. ft.

Such a house would be much easier to heat up than the frequently recommended farrowing-house with a floor-space of about 100 sq. ft. and a volume of some 1,000 cu. ft. or more which, with the insulation normally provided, is seldom likely to be more than 5° warmer inside than out when occupied by the average sow and litter. Our investigations suggest, therefore, that unless artificial heating is to be provided one should aim at using pens for rearing pigs which are not greater than about 150 cu. ft. in volume, and that the ventilation arrangements allow an air exchange of not more than 800 cu. ft. per hour; in addition it would be essential to provide adequate insulation of walls, roof, and floor, so that heat-losses by these routes is kept to a minimum.

It is obvious, too, from the same table that the space-allowance of some 200–400 cu. ft. per bacon pig is also unnecessarily large, and that in pens with outside runs floor-space of as little as 4·3 sq. ft. per 200-lb. pig and a capacity of 17 cu. ft. were satisfactory. As relatively small air-flows and space-allocations are satisfactory for this class of pig there is no difficulty in providing reasonable temperature conditions during cold weather without resorting to artificial heating.

Summary

1. In a high proportion of the piggeries sampled more or less at random it was found that poor results were obtained with litters and young stores during winter months.

2. The temperature-differences between outside and in were significantly different for the 'bad' and 'good' piggeries, the means being 5·9° and 13·3° F. respectively.

3. Unsatisfactory live-weight gains were being obtained during cold weather in fattening-houses where the temperature-differences between outside and in were small.

4. No housing conditions were encountered which appeared to be affecting the health and well-being of adult sows and boars.

5. Analysis of results showed that excessive heat-losses were mostly due to unnecessarily large air-flows; excessive cubic capacity per pig and the absence of effective insulation were also contributory factors.

6. Wherever the application of artificial heat to the rearing of litters was encountered, beneficial results were found to have followed.

7. Humidity, percentage of outside light entering buildings, and certain other criteria measured, did not correlate with differences in health or productivity.

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STUDIES ON THE FERTILITY OF GOLD COAST SOILS

PT. I. GENERAL ACCOUNT OF THE EXPERIMENTS

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A SERIES of fertilizer trials on the main annual food crops of the Gold Coast was laid down by the Agricultural Department in 1948, most of which were continued in 1949 when many new trials were started. The results of the trials in both years have been correlated with the climate and natural vegetation of the sites, their cropping history, and laboratory analyses of the soils; and a general account of this work is given in this series of papers.

When the first trials were laid down there was very little information available on the nature of the nutrient deficiencies of the country's soils, or on the responses that might be expected from the application of fertilizers. It was known that in the Northern Territories of the Gold Coast substantial responses were obtained from small dressings of kraal manure [1], and experiments in northern Nigeria, on similar soil to that of large parts of the Northern Territories, had indicated that responses to superphosphate might be expected [2].

In the first year there were 45 exploratory trials on the main annual food crops, covering a wide range of soil and climatic conditions. The effects of the main nutrients often deficient in soils were tested. A mulching treatment was also included. A standard 2^5 factorial design was adopted, and there was a single replication. The treatments were:

N Sulphate of ammonia: 0 and 2 cwt. per acre.
P Superphosphate (18·5 per cent.): 0 and 2 cwt. per acre.
K Muriate of potash: 0 and 2 cwt. per acre.
L Lime (CaO): 0 and 10 cwt. per acre (5 cwt. per acre on sites in far north).
M Mulch: 0 and 5 tons dry wt. of grass or straw per acre.

In the second year there were three developments.

(1) Sixteen new 2^5 NPKLM trials were started to cover further important soils.

(2) Twenty-four of the original trials were maintained under a rotation of crops.

Wherever it is possible there are now two 2^5 NPKLM trials on each of the important soils in the country. The trials are intended to remain for several years to find out how long the soils can maintain yields without addition of each of the major nutrients, and to what extent the yields decline if these nutrients are not supplied. The continued application of mulch will show the long-term effects of adding bulky organic matter to the soils. In the Northern Territories, dung at the rate of 4 tons per acre was substituted for mulch on one of the two trials at all places

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where cattle are kept. Lime was not reapplied in the second year. Otherwise the treatments were unchanged.

(3) Nitrogen and phosphate gave responses in the first year. Accordingly, 44 trials of a standard design were laid down to test the effects of different rates of application of N and P, and different times of application of N. A 3^3 factorial design with a single replication was adopted. The treatments were:

N Sulphate of ammonia: 0, 1, 2 cwt. per acre.
P Superphosphate (18·5 per cent.): 0, 1, 2 cwt. per acre.
T Sulphate of ammonia was applied in three ways: (e) early—at planting time; (l) late—at the first sign of flowering; and (s) split—half the dressing early, and the other half late.

As groundnuts had responded to lime, this crop received lime at the rate of 0, 5, and 10 cwt. per acre, instead of the time of application of nitrogen treatment.

Composite samples of the first and second 6 in. of all trial sites were taken, and their analyses have proved useful in interpreting the results of the trials. The following determinations have been made on all trial samples: gravel percentage, pH, total exchangeable bases, adsorbed phosphate (extraction with ammonium fluoride), and acid plus adsorbed phosphate (extraction with hydrochloric acid and ammonium fluoride). The total organic carbon and total nitrogen have been determined for the top 6 in. on all the 2^5 NPKLM trial sites.

There is a wide range of climate and soil conditions in the country, and a corresponding range of crops and methods of farming which may be briefly described at this point, and an indication given of the extent to which they have been covered.

Climate and natural vegetation.—Variations in the climate result in three main vegetation regions in the country: the dry coastal scrub and grassland area, the forest, and the savannah. They are shown on the attached map, which also indicates the places at which trials have been conducted.

In the forest area the average annual rainfall lies between 95 and 50 in. There are two well-marked rainy seasons which are distributed about monthly maxima in June and October. There is a dry season from December to March, and a dry spell in August between the two rainy seasons. The humidity is high throughout the year except for short periods in the dry season when the intensely dry Harmattan conditions prevailing in the north spread southwards. Except in the south-west, where the forest extends to the sea, the rainfall decreases towards the south, and there appears a transitional belt of poorly grown forest species described in this paper as Southern Fringing Forest. It is an important food-producing region with an average annual rainfall lying between 50 and 40 in. Farther south this merges into the dry coastal belt of grass and low scrub, which has too low a rainfall for intensive food-farming.

The boundary between the forest and the savannah to its north and east sides tends to follow the line of an escarpment that marks the junction of the Voltaian and Akwapimian sedimentary formations to the

north and east with the igneous rocks in the south. The average annual rainfall in the savannah ranges from 58 in. near the boundary of the forest to 39 in. in the far north-east. It is, however, the increasing length and severity of the dry season rather than the fall in total rainfall that

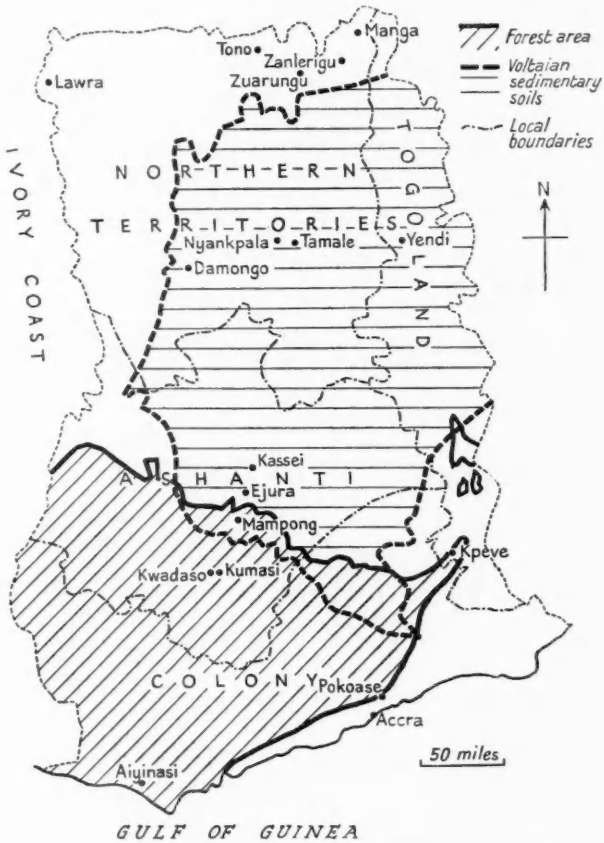

FIG. 1. Sketch map of trial sites in the Gold Coast.

causes a savannah vegetation to replace the forest. From the south to the north of the country the two rainfall peaks converge to a single maximum in August and September. In the south of the savannah, in North Ashanti, there are still two rainy seasons with an uncertain dry spell between. However, in Tamale there is only one rainy season, and this becomes more intense towards the far north. As the two rainy seasons merge, the dry season lengthens and at Tamale it lasts from mid-October until mid-April. The humidity through most of the dry season is very low.

Soils.—In the forest and southern fringing forest the most important soils are derived from granite. There are also important soils derived from greenstone, Lower Birrimian phyllites, Akwapimian quartzite and schist, recent unconsolidated sandy clays, and Voltaian sandstone.

In the savannah, the south and central parts are underlain by the Voltaian sedimentary rocks. The sandstones bear the important agricultural soils, the shale soils rarely being cropped. In the far north the most important soils are developed over granite; and there are other important areas underlain by greenstone. In spite of considerable variations in the underlying rocks a brief generalized description of the soil profiles may be given.

In nearly all cases the sites are on the upper or middle sections of moderate or gentle slopes, and except for some movement of the surface soils down the slopes the soils have been derived *in situ* from the rocks below.

The topsoil has, as a rule, been disturbed by cultivation to a depth of 4–8 in. It consists of a grey, orange, or reddish-brown loose sand or gritty sand and is darkened by a mild type of humus. The clay fraction has been largely removed by illuviation and the re-sorting of the finer particles by surface run-off. Below the surface horizon the content of clay gradually increases, the amount of humus drops fairly sharply, and the colour brightens. At varying depth below the surface there is an accumulation of gravel, consisting of concretionary iron and manganese oxides, sometimes consolidated to a hard pan, quartz derived from any quartz veins, and any resistant fragments of rock. The depth of the gravel horizon is of importance in assessing the fertility of the soil. On badly eroded soils it may be exposed on the surface, but on some sandstones it may lie below 6 ft. Below the gravel horizon usually lies a compact brown or grey sandy clay mottled with orange, yellow, and red colours. This merges at depth into the decomposing rock; though sometimes on flat bedded sandstones the gravel or pan may directly overlie the rock.

The surface soils are neutral or slightly acid, lying in the range pH 7·0–5·5. The behaviour of the pH down the profile reflects the variation of climate. In Ashanti and the Colony where humidity is high throughout the year, the acidity increases with depth. On the Voltaian soils of the Northern Territories there is little change in the acidity with depth; but in the far north where the dry season is most pronounced there is no thorough leaching of bases. These tend to accumulate in the lower horizons of the profile, which become neutral or slightly alkaline at depth.

The greenstone soils diverge considerably from this general picture. They consist of varying depths of friable orange or reddish-brown clays, with or without iron and manganese concretions, merging into the decomposing rock. They are exceptionally low in available phosphate.

Crops, Methods of Farming, and Distribution of Trials

In the forest, farmers are primarily interested in the growing of cacao. For subsistence food-farming the forest is cleared, maize, cassava, plan-

tain, and cocoyams interplanted, and harvested as they mature over the next two years; the land then reverts to forest. Sites at Kwadaso on granite and Lower Birrimain phyllites, at Cadbury Hall, Kumasi, on granite, at Aiyinasi on recent sandy clay, and Mampong on Voltaian sandstone are situate in such areas, and the sites at Kpeve on Akwapimian green schist are on the eastern fringe.

On the southern fringe of the forest food-farming is more important than cacao-farming, and first and second season maize is usually grown after the bush is cleared. In the second year maize will again be planted in the first season, and cassava either interplanted with the first-season maize or planted in the second season. The cassava matures in the third year and the land reverts to bush for about 2 to 5 years, depending on the pressure on the land. The sites at Pokoase on granite are in the heart of this area.

In the southern part of the savannah, in North Ashanti, many food crops are grown for export to the forest towns and villages. After clearing, yams (Dioscorea spp.) are invariably the first crop. They are planted between December and April and harvested between July and November. Many variations are practised in the subsequent cropping. A typical one would be, in the second year, upland rice on the moister soils, and on the drier soils maize in the first season and groundnuts in the second season. In the third year cassava may be planted and the land left to return to bush.

The central part of the savannah, in the Northern Territories, may be considered to stretch as far north as the junction of the Voltaian sedimentary rocks with the northern granites. There is only one season instead of two in North Ashanti. Yams are the first crop planted when the land is cleared. The mounds are usually interplanted with late millet. In the second year early maturing maize is interplanted with the late maturing guinea-corn or late millet or rice, and this cropping may be repeated for a third year or a crop of groundnuts or bambarra beans grown. The maize is planted at the end of April and harvested at the end of July. The other cereals are planted at the end of May or in June and harvested in November or December.

Cropping over the whole of the Voltaian rocks is largely confined to the sandstone soils, the soils developed over shale being either too shallow or too wet. Near the main centres the land is rested for about 2–5 years between each cropping period of about 3 years. There are, however, large areas in which the population is sparse and the resting-period may be between 5 and 25 years or more. The grass is burnt during the dry season. Rarely are cattle kraaled and use made of the dung.

The areas with a short resting-period are represented by sites at Tamale and Nyankpala and some sites at Yendi, all in the Northern Territories; and those with a long resting-period by sites at Ejura and Kassei in North Ashanti, and at Damongo and the remaining sites at Yendi in the Northern Territories. All these sites are on sandstone except two at Nyankpala on shale.

In the far north, excluding the Lawra area in the west, there is a considerable difference in the agricultural system practised. The compounds

are scattered, and an area of between 5 and 15 acres around each compound is cropped continuously with the aid of household refuse and excreta from cattle, sheep, goats, and humans. Beyond the range of these fertility supplements there is a non-compound farm in which the fertility is maintained by a resting-period of about 3 years. On the compound farm a typical rotation is early millet and guinea-corn in the first year, early millet and late millet in the second, and groundnuts or bambarra beans in the third. The climate is too dry for yams, and early millet takes the place of the maize grown farther south. Any dung available is supplied to the cereals, usually the guinea-corn. On the non-compound farm guinea-corn and late millet are planted without early millet.

Sites at Tono, Zuarungu, and Manga represent the important granite soils of this region, and two sites at Zanlerigu the soils developed over greenstone.

No experiments have been carried out in the Lawra District in the far north-west.

Methods of applying fertilizers.—Two methods of application have been used: broadcasting, and running in a line about 4 in. wide on top of the planting ridges shortly before planting.

No depression of germination or delay in early growth has been noted when the fertilizers have been broadcast and the planting has been done on the flat, or broadcast and the soil subsequently ridged and the planting done on top of the ridge (except yams at Damongo).

When the fertilizers have been applied in a line on top of the ridge, depression of germination and early growth has frequently been caused by muriate of potash and sulphate of ammonia, but not by superphosphate. The effect is particularly noted at a dry planting-time. Muriate of potash has a worse effect than sulphate of ammonia, and groundnuts are more sensitive than cereals.

The effect on the final yield of such germination depressions was not so serious as it might be on native farms, because all vacancies were filled with fresh seed or transplants from the same plot.

Presentation of experimental results.—In the subsequent parts of this series the effects of each of the experimental treatments are discussed in turn. For each treatment the sites have been grouped according to major divisions of climate and vegetation, soil type, and cropping history, in order to show interesting differences or similarities. These divisions are:

1. Forest and Southern Fringing Forest: (*a*) Undisturbed sites; (*b*) Disturbed sites.
2. Savannah. Voltaian soils: (*a*) Long resting-period sites; (*b*) Short resting-period sites.
3. Savannah. Granite soils of the far north.
4. Savannah. Greenstone soils of the far north.

The division of the forest soils between disturbed and undisturbed sites calls for comment as it is particularly important for any consideration of the effects of phosphate. It was unfortunate that trials were

begun on some sites in forest in 1948 before it was realized how seriously their fertility was influenced by people living on or near them many years ago. In the more populated areas the frequent removal of villages and of small farm-camps has probably led to large numbers of these high fertility pockets. Nearly all the sites separated as 'disturbed' have a record of human interference in their history, or there is evidence of it in the form of pieces of pot in the profile. They also all satisfy the arbitrary criteria of a pH value greater than 6·5 in the surface soil, an acid-plus-adsorbed-phosphate value greater than 10 p.p.m., and a ratio of acid+adsorbed:adsorbed phosphate greater than 2·5 (to be discussed under Phosphate in Part III), and a relatively high content of exchangeable bases. There are not sufficient forest sites to group them according to the different rocks underlying them.

The divisions in the savannah follow from the above discussion of cropping systems and soils.

Acknowledgements

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Summary

In this introductory Part the methods used in the fertilizer trials of 1948 and 1949 are described briefly; the climate, soils, and farming systems are outlined; methods of applying fertilizers and the mode of presenting results are discussed.

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FERTILIZER TRIALS WITH GROUNDNUTS IN NORTHERN NIGERIA

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WITH PLATES 6, 7, 8

THE annual export of groundnut kernels from Northern Nigeria has averaged 300,000 tons during the past five years (1945–9). Exports represent a yearly drain of 11,000 t. of nitrogen (55,000 t. sulphate of ammonia) and 3,000 t. of phosphoric anhydride (17,000 t. of single superphosphate) from soils which have been shown to be markedly deficient in phosphate [1].

Groundnuts (*Arachis hypogaea* L.) are not manured in any of the peasant systems of agriculture. In the intensive farming practised in the built-up area surrounding Kano (12° N.: 8° 30′ E.), the centre of the groundnut trade, it is usual for one year of unmanured groundnuts to follow and be succeeded by two years of sorghum and millet, to which all available forms of organic manure and household refuse are applied. In rural areas, in which land is periodically rested under naturally regenerated cover, groundnuts usually form the last course of a variable rotation during which any surplus of manure from the compound farm (kitchen-garden) is applied to the grain crops; in times of high prices two successive crops of groundnuts may be taken before the land is allowed to revert to 'bush' fallow.[1]

It was therefore natural that cereals should receive first attention in the early fertilizer trials whereby Hartley [1] showed that the spectacular returns produced by the application of 1 t. of pen manure per acre to the soils of Zaria Province [2] could equally be obtained by the use of 50 lb. superphosphate. When the last war brought fertilizer work to a standstill Hartley had, however, not only shown that cereals made similar response to superphosphate in Katsina and Kano Provinces, representing an important part of the groundnut area; he had obtained promising response from the direct application of superphosphate to groundnuts on average land, and had shown that on these sandy soils [3] groundnuts derived greater benefit from the residual effect of superphosphate than from the residual effect of an equivalent amount of pen manure [4].

At the time of the visit of the W. African Oilseeds Mission of 1946 [5] it was possible to predict that on soils of average fertility (kernel yield 700 lb. per acre or under) the application of 50 lb. superphosphate would give an added return of 200 lb. kernels per acre. At prices then prevalent

[1] There are good indications that groundnuts are much less exacting than sorghum in their manurial requirements. Both crops have been grown in monoculture at Kano on plots which have received no manure since 1931. Mean annual yields per acre of sorghum grain, which started at 709 lb. in 1931, have been: (1) 1931–3 = 301 lb.; (2) 1939–41 = 141 lb.; (3) 1947–9 = 99 lb. By contrast the yields of groundnut kernels have been: (1) 1931–3 = 972 lb.; (2) 1939–41 = 740 lb.; (3) 1947–9 = 230 lb.

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the use of superphosphate promised economic returns which the continued rise in oil-seed prices has subsequently enhanced. At the present time (March 1951) superphosphate can be landed in Kano at £20 per ton, which is also the current price for groundnuts. The farmer may therefore expect a fourfold return for his expenditure on fertilizers.

The Oilseeds (Groundnut) Mission of 1947 [6] unhesitatingly recommended the issue of phosphatic fertilizers to peasant farmers as one of the surest means of maintaining or increasing groundnut production without jeopardizing the supply of local foodstuffs or making inroads into the land reserves needed for a rapidly expanding population. They recommended experiments to find safe and simple methods of fertilizer application which would enable the farmer to obtain full benefit from the small dosage which he would be using, and urged the trial of the more concentrated phosphatic fertilizers, which by virtue of their lower transport charge per unit of phosphate would increase the farmer's margin of profit. The present paper gives an account of some of these experiments.

Placement trials, using superphosphate in powder form, had been begun in 1947 before the arrival of the Groundnut Mission. They showed that increments of the order prophesied for average land could be obtained by the use of 50 lb. superphosphate on some soils already yielding upwards of 1,000 lb. kernels per acre. Similar results obtained over a large part of the groundnut area with pelleted phosphates, which the Mission helped to make available for extended trial by farmers in 1948 and 1949, led the North Regional Development Board of Nigeria to institute in 1949 a Fertilizer Distribution Scheme whereby groups of farmers, totalling 40,000 per annum, receive free of charge a specially prepared 56-lb. bag of single superphosphate. Distribution is to take place in each of five successive years, of which 1950 was the first. In the year following free distribution, fertilizer is made available against payment to those farmers who have found its use attractive [7].

The issue of single superphosphate in preference to the more concentrated phosphatic fertilizers has been dictated by finding that the gypsum contained in single superphosphate has not only a positive effect on kernel production: it has an outstanding effect on the size of plants which, apart from the value of the haulms as fodder, greatly assists the peasant farmer in appreciating the efficacy of the fertilizer. This effect, which is of great importance in view of the present world shortage of sulphur, is still being studied.

Nitrogenous Fertilizers

The Mission of 1946 considered that as groundnuts are legumes the provision of nitrogenous fertilizers would be unnecessary (loc. cit., p. 10). The 1947 Mission had, however, been advised that small quantities of nitrogen, of the order contained by monammonium phosphate, gave the young seedlings a good start, which was helpful in reducing the incidence of rosette disease.

No data for the effect of small dosages of nitrogen were available from the early Nigerian fertilizer trials. Many had been made in simulation

of pen manure with a wide N/P_2O_5 ratio, e.g. 24 lb. N. : 8 lb. P_2O_5 : 20 lb. K_2O per acre. With most crops, including groundnuts, there had been little or no direct response to nitrogen, but a marked positive interaction between nitrogen and phosphate; potassium had usually been depressant, and no significant response to potassium has yet been obtained in the Northern Provinces.

1. *Monammonium phosphate*

Pot experiments were made in 1947 to determine the optimum method of placing pellets of various phosphatic manures, including monammonium phosphate (12:55), with groundnut seed. In every case young seedlings (up to 30 days old) showed a greater response to monammonium phosphate or to superphosphate+sulphate of ammonia than to single superphosphate or triple super [8]: the differences were significant unless soils of very low phosphate status were used.

Comparative field trials of pellets of monammonium phosphate and triple superphosphate, each containing the equivalent of 11 lb. P_2O_5 per acre, were made in Daura (13° N.: 8° 20′ E.), Kano and Kontagora (10° 25′ N.: 5° 30′ E.) in 1948. In Samaru (Zaria 11° 4′ N.: 7° 42′ E.) these pellets were tested against similar pellets of single superphosphate and bone phosphate in 1948, and pellets of sulphate of ammonia+triple super (6:30) in 1949. In none of these trials were the yields of kernels or haulms produced by monammonium phosphate significantly greater than those from triple super. The incidence of rosette disease at Kontagora, the only site badly affected, was too irregular to permit any assessment of fertilizer effect: the most seriously affected plot was one receiving monammonium phosphate.

Wet weights were determined for sample plants taken from the 1948 Samaru trial at 30 and 60 days. At both dates there were highly significant increases due to monammonium phosphate and single super, but to no other treatment. The increases were not themselves significantly different, but whereas the monammonium phosphate plants were heavier at the first weighing, they had at the second weighing fallen behind the single-super plants, which subsequently outstripped them to give significantly greater yields of kernels and haulms at harvest (*v.* Table 6).

TABLE 1. *Wet weights (gm.): Whole Plants from 72 Stands*

Treatment	*30 days*	*60 days*
No manure	2,063	14,635
Monammonium phosphate . .	+772 (37·4%)	+5,578 (38·1%)
Single super	+621 (30·1%)	+6,590 (45·0%)
Sig. diff. (1%)	461	4,609

The relative merits of monammonium phosphate and a mixture of triple super and sulphate of ammonia containing equivalent amounts of nitrogen and phosphate are discussed at p. 232.

2. *Sulphate of ammonia*

Placement trials with 0:50:100:200 lb. single superphosphate powder per acre were made with both cereals and groundnuts at centres in 1947 (*v.* Table 10 for sorghum at Kano). They suggested that the maximum economic return would be given by the use of 50–100 lb. superphosphate per acre, an amount which it was thought the peasant farmer could afford to buy without direct subsidy. The interaction of superphosphate and sulphate of ammonia was first tested, therefore, by using 0:50:100 lb./acre superphosphate and similar rates of sulphate of ammonia. Fifty-four plot trials were made in 1948 at Damaturu (12° N.: 12° E.) and Kontagora, on newly cleared sites in underpopulated areas which the Groundnut Mission had recommended for development. Superphosphate was applied in a thin line in a channel along the ridge before planting, and sulphate of ammonia was ringed round the seedlings at 20 days.

TABLE 2. *Interaction of Superphosphate and Sulphate of Ammonia: Kernel and Haulm Weights (lb. per acre)*

KONTAGORA

	Kernels				*Haulms*			
	*p*0	*p*1	*p*2	*Mean*	*p*0	*p*1	*p*2	*Mean*
*n*0	660	1,019	1,182	954	647	1,157	1,525	1,109
*n*1	1,038	1,234	1,352	1,208	1,377	1,560	1,793	1,577
*n*2	1,002	1,151	1,332	1,162	1,390	1,520	1,750	1,553
Mean	900	1,135	1,289	(1,108)	1,138	1,412	1,689	(1,413)

Main effects and interaction sig. at 1%. *L.S.D.* means: 1% = 66; 5% = 49. Single treatments: 1% = 115; 5% = 86.

Main effects and interaction sig. at 1%. *L.S.D.* means: 1% = 101; 5%=75. Single treatment: 1% = 175; 5% = 131.

DAMATURU

	Kernels				*Haulms*			
	*p*0	*p*1	*p*2	*Mean*	*p*0	*p*1	*p*2	*Mean*
*n*0	651	948	987	862	655	747	680	694
*n*1	644	813	899	785	570	651	625	615
*n*2	431	900	930	754	717	613	758	696
Mean	575	887	939	(800)	647	670	688	(668)

Main effects sig. at 1%. Interaction not significant. *L.S.D.* means: 1% = 148; 5% = 113. Single treatment: 1% = 257; 5% = 197.

No significance.

It will be seen that at both sites 50 lb. superphosphate gave gratifying increases in kernel weights, the increment over No Manure being +349 lb. (53%) at Kontagora and +297 lb. (46%) at Damaturu. The further increment given by 100 lb. was significant at Kontagora (+163 lb.), but not at Damaturu, where neither rate had any effect on haulm-weight.

The response to sulphate of ammonia was markedly different at the two sites. At Damaturu nitrogen proved depressant, though significantly so (P = 5%) only in respect of the 100 lb. application made in the absence of phosphate. At Kontagora there was direct response to 50 lb. of sulphate of ammonia of an order not previously encountered; the increment over No Manure was +378 lb. kernels (57%) and +730 lb. haulms (113%): returns from 100 lb. per acre were smaller but not significantly so. Similar response was shown by sorghum planted in a parallel trial: 50 lb. sulphate of ammonia gave an increment of 221 lb. dry grain (26%) over a non-manured yield of 841 lb.

This direct effect of sulphate of ammonia was of interest because in his reconnaissance of the Kontagora area the Soil Scientist (Dr. H. Vine) had remarked on the general chlorosis of the grain crops, which he had attributed to planting too late after the nitrate peak which accompanies the early rains [2].

Interaction (NP)

1. *Kontagora: Kernels and Haulms.* It will be seen that at Kontagora the effect of sulphate of ammonia is less in the presence of superphosphate than in its absence. This negative interaction is highly significant (P = 1 per cent.) in respect of both kernels and haulms. It appears to be due to the property of stimulating nodule activity or general growth shared by sulphate of ammonia and the gypsum present in single superphosphate. This very important effect is discussed under Gypsum at page 233.

Similar negative interaction between superphosphate and sulphate of ammonia was recorded by Nye [9] in 1948 for certain Gold Coast soils on which groundnuts showed direct response to sulphate of ammonia.

TABLE 3. *Mean Response to Sulphate of Ammonia (75 lb. per acre): Kontagora*

Superphosphate	*Kernels (lb./acre)*		*Dry haulms (lb./acre)*	
(i) Absent . . .	+360	*Diff.*	+737	*Diff.*
(ii) 50 lb. . . .	+173	−187**	+383	−354**
(iii) 100 lb. . . .	+160	−200**	+247	−490**

(** = significant at 1%)

2. *Damaturu: Shelling percentage.* In contrast to Kontagora the interaction between superphosphate and sulphate of ammonia at Damaturu was positive in respect of kernel yields though not significant. The presence of a large number of 'blind' nuts in the Damaturu crop suggested the analysis of the percentage kernel/nut at both sites. Whereas at Kontagora the percentage ranged from 72·7 to 75·2 and was not influenced by fertilizer treatment, at Damaturu there was a highly significant depression due to 50 lb. sulphate of ammonia and a significantly greater depression due to 100 lb.; both 50 lb. and 100 lb. superphosphate produced significant increases of the same order. Interaction between sulphate of ammonia and superphosphate was positive, mainly due to

the counteraction by 50 lb. superphosphate of the big depression caused by 100 lb. sulphate of ammonia.

TABLE 4. *Percentage Kernel to Nut: Damaturu*

			Sig. diff.
$n0 = 68{\cdot}0$	$n1 = 63{\cdot}7$	$n2 = 61{\cdot}0$	1% = 2·26
$p0 = 60{\cdot}5$	$p1 = 65{\cdot}9$	$p2 = 66{\cdot}4$	5% = 1·69

Mean response S/A			*Mean response Super*		
Super absent	−9·0	*Diff.*	S/A absent	+2·3	*Diff.*
,, 50 lb.	−4·1	+4·9**	,, 50 lb.	+4·5	+2·2 (n.s.)
,, 100 lb.	−4·0	+5·0**	,, 100 lb.	+10·1	+7·8**

Groundnuts are sensitive to contact with very small amounts of sulphate of ammonia (cf. p. 238), and it is probable that its adverse effect at Damaturu resulted from its application during a period of drought. The positive interaction between sulphate of ammonia and superphosphate may therefore belong to the dubious kind which had previously been observed when heavy applications (3 cwt. per acre) of sulphate of ammonia had been made to sorghum seedlings during dry periods: there was general set-back, but the effect was mainly remarked on the smaller seedlings, i.e. those not receiving phosphate.

The growing-season of 1948 was, however, abnormally short in the northern areas represented by Damaturu, and it seemed possible that the reduced shelling percentage caused by sulphate of ammonia might have been the result of delayed maturation.

Samaru 1949: Sulphate of ammonia: length of season.—The effect of 100 lb./acre of sulphate of ammonia on the growth-rate and shelling percentage of a short-season crop was therefore tested at Samaru in 1949 on groundnuts planted (1) at the normal time, (2) 2 weeks later, and (3) 4 weeks later. Parallel treatments included: (*a*) No manure, (*b*) 100 lb. superphosphate, (*c*) 100 lb. super + 100 lb. S/A. There were 4 replicates of each treatment.

Sulphate of ammonia was found to cause a significant lag in flowering: thus at 35 days the number of flowers per treatment (30 sq. yds.) was: No manure = 193: N = 50: P = 492: NP = 299. Sig. diff. 1% = 216. But it had no effect on shelling percentage (O = 71·4; N = 71·1; P = 70·9; NP = 70·9), and caused no significant reduction in kernel or haulm yields whether applied in the presence or absence of phosphate.

The yields are worth quoting as they illustrate very well the losses entailed by delayed planting. The Department has for many years been conducting propaganda for early planting in respect of both groundnuts and cotton; the advice has fallen on ears deafened by the need to ensure the welfare of subsistence crops before cash crops are given attention. It will be seen that the over-all yield of kernels at the first planting is 39 per cent. greater than that from the second planting, which is in turn 69 per cent. greater than that of the third planting. On the unmanured plots the yield from the first planting (890 lb.) is three times as great as that from the third (286 lb.).

The increment of 610 lb. kernels (69% of No manure) due to 100 lb. superphosphate at the first planting is a most notable one, as is the increase of 678 lb. haulms (100% of No manure) at the third planting; the haulm yield from plants given superphosphate at the third planting is in fact equal to that from unmanured plants from the first planting.

TABLE 5. *Planting Date: Effect of NP: Samaru, 1949*

	Kernels (lb./acre)				*Dry haulms (lb./acre)*			
Treatment	*June 21*	*July 5*	*July 19*	*Mean*	*June 21*	*July 5*	*July 19*	*Mean*
No manure .	890	518	286	565	1,274	1,077	678	1,010
100 lb. S/A .	736	688	393	606	1,368	1,225	844	1,146
100 lb. super .	1,500	1,065	549	1,038	1,816	1,629	1,356	1,600
100 lb. S/A + 100 lb. super	1,424	1,006	718	1,049	2,261	1,800	1,315	1,792
Mean . .	1,138	819	486	(814)	1,680	1,433	1,048	(1,378)

Sig. diff. Single treatment: 1% = 362; 5% = 269.

Sig. diff. Single treatment: 1% = 441; 5% = 328.

Type of Phosphate

Of the £20 per ton quoted as the current Kano price for single superphosphate powder no less than £8 represents freight charges: £3 for sea and £5 for rail transport. From Kano or other rail-centres fertilizers may need to travel a distance of up to 300 miles by road at a cost of at least 6*d*. per ton mile. The Groundnut Mission's anxiety to test the effect of the more concentrated fertilizers, which would for the same transport-cost present the farmer with from $2\frac{1}{2}$ to 3 times the amount of phosphate contained in single super, will therefore be appreciated.

Samaru 1948: Type of phosphate: method of placement.—Reference has already been made to trials in 1948 of monammonium phosphate versus triple super. The first field trial of these two fertilizers against single superphosphate was made at Samaru in 1948. Pellets of (1) single superphosphate, (2) bone phosphate, (3) triple super, and (4) monammonium phosphate had been obtained of such a size that all gave the equivalent of 11 lb. P_2O_5 (60 lb. single super) per acre when applied singly to stands of groundnuts planted 9 in. × 3 ft. There were 6 replicates of 9 treatments, which consisted of (1) No manure and (2–9) each type of pellet placed (*a*) accurately by a dibbling stick, (*b*) by a modification of the local method of planting with the toe. (There was no significant difference between placement treatments, which are omitted in Table 6.)

The result was entirely unexpected. Single superphosphate not only produced a significantly greater yield of kernels than any other treatment, it had an amazing effect on haulm yield. It has been noted that at 60 days plants receiving superphosphate began to outstrip plants receiving ammonium phosphate: their foliage subsequently became greener and stronger than that of all other treatments, the final

increment of 455 lb. haulms representing an increase of 37·4 per cent. over No manure.[1]

TABLE 6. *Type of Fertilizer: Samaru, 1948*

Treatment	*Kernels (lb./acre)*			*Dry haulms (lb./acre)*	
No manure . . .	*1,200*	*Diff.*		*1,216*	*Diff.*
Bone phosphate . .	1,342	+142*	*Diff.*	1,255	+37
Triple super . . .	1,448	+248**	+106*	1,273	+57
Amm. phosphate . .	1,467	+267**	+125*	1,246	+30
Single super . . .	1,571	+371**	+229**	1,681	+455**
Sig. diff. 1% . . .		149**	126**		231**
5% . . .		113*	94*		173

Reports of a similar foliar effect due to gypsum at Kontagora, Kano, and Daura were received in time to try the effect of gypsum dust on discard rows of plants receiving triple super, bone phosphate, and no manure: plants of these treatments were chlorotic, particularly so in parts of the field that were badly drained. Although plants were then approaching senescence their foliage showed a marked darkening within 14 days of dusting with gypsum.

Single v. *Triple Super*

Subsequently many comparative trials have been made of single versus triple superphosphate both in pellet and powder form; in every case single super has proved superior both in kernel and haulm production, though the differences in kernel weight have not often been of a high order.

Three considerations have counselled the issue, for the present, of single super in preference to triple. The first is its foliar effect, which helps the farmer to a quick appreciation of its value. The second is its less detrimental action on groundnut seed should it make contact during placement (p. 238). The third is its residual effect, to whose duration its gypsum-content is probably contributory (p. 237). (The residue of gypsum left by single superphosphate pellets, even under fairly high rainfall, has caused the farmer needless perturbation, as he has imagined either that the fertilizer was unacceptable to the plant or had been applied in excess of its requirements.)

It will be seen under Gypsum (p. 236) that triple super containing small quantities of sulphate of ammonia is a potential substitute for single super, and it is possible that its immediate effect will be greater in areas of low rainfall. Pellets containing a mixture of sulphate of ammonia and triple super (6% N : 30% P_2O_5) were used at Samaru in 1949 on randomized strips (6 replicates of each treatment) laid down to demonstrate the effect of various kinds of pellet to the farmer.

[1] Haulm-weights recorded at harvest tend to give an under-estimate of foliar effect on account of the leaf-shedding that occurs during ripening. In the present experiment leaves began to shed on October 9; haulms were not collected until November 2. (Contrast also photographs and weights of haulms at Kontagora (Plate 6, Figs. 1 and 2, and Table 8).)

The strips were very small (8 sq. yds.); they were planted very late (July 12); they were badly waterlogged during the last week in August, and there had been no intention of recording yields until it was noticed that the plants receiving monammonium phosphate (12:55) were highly chlorotic and undersized, whilst those receiving sulphate of ammonia had the vigour and dark colour shown by plants treated with superphosphate. The comparison was of great interest because with a uniform dosage of 11 lb. P_2O_5 per acre the amounts of nitrogen supplied by the two fertilizers were almost identical (S/A = 2·2: M.A.P. = 2·4 lb./acre). The precision of the experiment was sufficient to demonstrate a significant difference in haulm-weight between the two treatments.

TABLE 7. *Type of Fertilizer: Samaru, 1949*

Treatment	*Kernels (lb./acre)*		*Dry haulms (lb./acre)*	
No manure	302	*Diff.*	648	+113
Triple super	450	+148*	659	+124
M.A. phosphate	456	+154*	535	*Diff.*
Triple+S/A	483	+181*	839	+304*
S. super (L.P.)	509	+207**	833	+298*
S. super (H.P.)	512	+210**	835	+300*
Sig. diff. 1%		192**		..
5%		141*		214*

(L.P., H.P. = Pellets of single super made at low and high pressures.)

Gypsum

The Groundnut Mission had drawn attention to the high calcium-content of groundnuts, and had advocated (loc. cit., p. 28) trials of gypsum dusts, which in the United States had been found to give substantial increases in kernel weights, the effect on kernel size and shelling percentage being particularly marked [10].

Gypsum was first used in the trials of monammonium phosphate versus triple superphosphate pellets made at Daura, Kano, and Kontagora in 1948 (p. 227). Each type of pellet was tested against No manure in the presence and absence of a quantity of sulphate of ammonia (16 lb./acre) containing nitrogen roughly equivalent to that contained in the monammonium-phosphate dressing. There were 5 replicates of each of these 6 main treatments: gypsum was applied at 100 lb. per acre as a dust to the foliage of half-plots of all treatments 60 days after planting.

At all three sites there was a marked response to gypsum, reflected in the dark-green colour and enhanced growth of the foliage. The effect was greatest at Kontagora (Plate 6, Figs. 1 and 2), which provided the only results of sufficient precision to give over-all significance. The Kontagora results are given in Table 8 as means for half-plot treatments.

This experiment was unfortunately planted very late, 26 days after the parallel sulphate of ammonia *v.* superphosphate trial (Table 2) from

which it is distinguished by several features: (i) the lower ratio of kernels to haulms; (ii) the lower percentage of kernel to nut, with a consistent though non-significant depression of shelling percentage due to sulphate of ammonia; (iii) the failure of sulphate of ammonia to produce any increase in kernel weight in the absence of phosphate, and vice versa.

TABLE 8. *Interaction of Sulphate of Ammonia and Gypsum with Triple Super and Ammonium Phosphate: Kontagora, 1948*

Added	*Nil*	*S/A*	*Gypsum*	*S/A+G*	*Mean*	
(1) *Kernels lb./acre*						
No manure .	635	617	716	719	672	For ½-plot single treat. *L.S.D.* 1% = 199 5% = 140
Triple . .	602	779	716	855	739	
Amm. phos. .	642	787	817	878	781	
Mean . .	626	728	750	818	731	
(2) *Haulms lb./acre*						
No manure .	776	1,236	1,184	1,224	1,105	Single treat. *L.S.D.* 1% = 625 5% = 462
Triple . .	838	1,380	1,284	1,712	1,303	
Amm. phos. .	1,075	1,621	1,280	1,732	1,427	
Mean . .	896	1,412	1,249	1,556	1,278	
(3) *Kernel percentage*						
No manure .	69·0	65·5	67·2	67·4	67·3	Not significant
Triple . .	67·5	67·1	69·9	68·0	68·1	
Amm. phos. .	67·4	66·0	68·3	67·5	67·3	
Mean . .	68·0	66·2	68·5	67·6	67·6	

It will be seen that though gypsum failed to give the expected increase in shelling percentage (gypsum = 68·0: no gypsum = 67·1), it gave highly significant increases both of kernels and haulms. Main effects (increases over no gypsum) were: (i) kernels = +106 lb. (15·6% sig. 1%), (ii) haulms = +249 lb. (21·6% sig. 2%). The effects are not significantly different from those given by 16 lb. sulphate of ammonia: (i) kernels = +84 lb. (12·2% sig. 1%), (ii) haulms = 411 lb. (38·3% sig. 1%); and it will be noticed that there is a marked negative interaction between gypsum and sulphate of ammonia, particularly in regard to haulm production. This interaction was significant in an experiment made at Kontagora in 1949 when 0:25:50 lb. of both gypsum and sulphate of ammonia were applied to the soil in the presence of 0:20:40 lb. triple super per acre.

The gypsum effect was quite different from that expected from calcium, which is operative at the time of maturation and can arise by absorption through the gynophores [11]. The spectacular increase in haulm-growth is similar to that observed when gypsum has been applied to legumes and crucifers in rural areas of the United States whose soils suffer from sulphur deficiency [12]. It is hoped to determine the relative contributions made by calcium and sulphur to the gypsum effect during the coming year: the fact that a similar effect can be induced by

ammonium sulphate but not by monammonium phosphate (p. 233) suggests that sulphur may be the dominant factor.

The experiment had one very practical implication; that in the absence of a local source of gypsum it would be advisable to import single rather than triple super unless lime could be shown to have a comparable effect. Only one trial of lime versus gypsum has been made. At Samaru in 1949 applications of freshly ignited and slaked lime equivalent to 100 lb. gypsum per acre (43 lb. $Ca(OH)_2$) were made both to the roots and foliage (dust at 60 days) of groundnuts receiving (i) no manure, (ii) triple super pellet, (iii) single super pellet; gypsum was applied similarly. There were 4 replicates of 15 treatments.

In contrast to gypsum, which in the presence of triple super produced significant increases of both kernels and haulms, lime had no effect on yield and caused no abatement of the chlorosis shown by plants receiving triple super (Plate 7, Fig. 6). The solubility of calcium hydroxide is not much less than that of gypsum, and though it was probably converted rapidly to the insoluble carbonate the leaf-dust might have been expected to have had some effect if the calcium effect were an important one.

TABLE 9. *Interaction of Lime and Gypsum with Single and Triple Super: Samaru, 1949*

Kernels (lb./acre)

	No Calcium	*Lime*		*Gypsum*		*Mean*	
		Roots	*Foliage*	*Roots*	*Foliage*		
No super	909	1,006	961	966	1,007	970	Sig. diff.
Triple	1,270	1,228	1,200	1,418	1,474	1,318	Single treat.
Single	1,364	1,281	1,305	1,265	1,394	1,322	1% = 243 lb.
Mean	1,181	1,172	1,155	1,216	1,292	(1,203)	5% = 182 lb.
Dry haulms (lb./acre)							
O	1,058	1,059	1,086	1,192	1,168	1,112	Sig. diff.
T	1,171	1,162	1,153	1,310	1,403	1,240	Single treat.
S	1,325	1,258	1,189	1,274	1,423	1,294	1% = 229 lb.
Mean	1,184	1,159	1,143	1,259	1,331	(1,215)	5% = 171 lb.

Other experiments made with gypsum in 1949 and 1950 have shown that its effect is variable. At *Samaru*, where applications of phosphate and gypsum corresponding to dressings of 50:100 lb. superphosphate have been made by using sodium dihydrogen phosphate (20:40 lb.) and gypsum (25:50 lb.) it has been shown in two successive years that:

(i) *Phosphate alone* produces large increases in kernel yields but has no significant effect on haulm-weight (Plate 7, Fig. 5).

(ii) *Gypsum alone* has no significant effect on either kernel or haulm-weight (Plate 7, Fig. 5).

(iii) There is a marked positive interaction between gypsum and phosphate which leads to a further substantial increase in kernel yield when gypsum is added to plots receiving phosphate (e.g.

1949, $p1 = 978$: $p1g1 = 1{,}260$, $p2 = 1{,}158$: $p2g2 = 1{,}470$ lb./acre) and a very high increase in haulm-weight ($p1 = 1{,}270$: $p1g1 = 2{,}160$, $p2 = 1{,}340$: $p2g2 = 2{,}340$ lb./acre) (Plate 6, Fig. 3; Plate 7, Fig. 4).

At *Kontagora*, where triple super has been used in place of sodium phosphate, it has been confirmed that gypsum has a direct effect on both kernel- and haulm-weights and makes no significant gain from interaction with phosphate, which in 1950 had itself no direct effect. Increments due to 50 lb. gypsum were:

(1) *Kernels.* No manure = 373. Gypsum = +149 (Sig. 1%)
Triple super = 422. Gypsum = +198 (Sig. 1%)

(2) *Haulms.* No manure = 466. Gypsum = +260 (Sig. 1%)
Triple super = 553. Gypsum = +280 (Sig. 1%)

There was also lack of response to phosphate in a similar experiment made at *Kano* in 1950. Here 50 lb. gypsum had no effect on kernel yield but produced increments in haulm-weight of (*a*) +206 lb. over No manure (1,439 lb.) and (*b*) +186 lb. over triple super (1,532 lb.) (Sig. diff. 1% = 195; 5% = 146).

These experiments have shown that the use of gypsum in quantities exceeding those present in single superphosphate is unlikely to be generally economic. Parallel treatments by sulphate of ammonia, which were included in all experiments, have indicated that weight for weight sulphate of ammonia has a higher efficiency than gypsum in respect of both kernel and haulm production. Should the present shortage of sulphur lead to difficulty in obtaining single superphosphate some economy in sulphur utilization may be found in the use of triple super containing very small amounts of sulphate of ammonia.

Residual Effects

Although the Fertilizer Distribution Scheme has been financed from funds contributed by the Groundnut Marketing Board there has been no insistence that superphosphate shall be applied only to groundnuts. Early demonstrations were made mostly with groundnuts, but the farmer has been encouraged to try superphosphate with other crops, and it is likely that the present practice of applying organic manure only to the grain crops will eventually be modified to include fertilizers.

Acquiescence in this practice has been prompted by the very conspicuous ability of groundnuts to pick up a residual effect from applications of superphosphate made to grain-crops in previous years. Mention has already been made (p. 235) of an experiment in which the residual effect of superphosphate (200 lb. per acre) was found to last 4 years, whilst the residual effect of an equivalent dressing of 3 tons pen manure lasted only 1 year.[1] This experiment was begun in Kano in 1937 by applying manures to the first member of a 3-course rotation—millet: sorghum: groundnuts. The residual effect of 200 lb. super on ground-

[1] War-time exigencies caused this experiment to be prematurely abandoned; there was promise of a continued effect from superphosphate [4].

nuts planted in 1939 was: kernels = +188 lb. (24% of No manure) haulms = +198 (19% of No manure).

Residual effects with groundnuts have since been obtained from quantities of superphosphate less than 200 lb./acre (Plate 8, Fig. 9). Thus, in experiments already quoted, (i) *50 lb. super* applied to sorghum at Kontagora in 1948 (p. 228) gave an increment of 141 lb. groundnut kernels (20% of No manure) in 1949; (ii) *100 lb. super* applied to groundnuts at Samaru in 1949 (Table 5) gave increments of 236 lb. kernels (34% of No manure) and 251 lb. haulms (28% of No manure) in 1950.

Kano has again provided a good example of the lengthy duration of the residual effect of superphosphate. In 1947 superphosphate at 0:50:100:200 lb./acre was mixed with soil and applied to sorghum either by (i) placement in the planting-hole, or (ii) placement in a narrow channel along the centre of the ridge immediately prior to planting (7×7 Latin square). The residual effect has been tested by groundnuts in 1948–9–50.

TABLE 10. *Direct and Residual Effects of Superphosphate (lb./acre): Kano, 1947–50*

Treatment	*1947 Sorghum grain*	*1948 Groundnut kernels*	*1949 Groundnut kernels*	*1950 Groundnut kernels*
No manure . .	776	827	472	455
Super 50 lb. (line) .	+123	+232**	+138**	+88
,, 100 ,, .	+323**	+383**	+193**	+101
,, 200 ,, .	+361**	+438**	+170**	+125
Super 50 lb. (hole) .	+341**	+390**	+208**	+105
,, 100 ,, .	+348**	+226**	+169**	+76
,, 200 ,, .	+365**	+359**	+138**	+73
Sig. diff. 1% . .	258	135	122	No manure *v.* Combined manures. Sig. diff. 1% = 80

Residual effects have also been obtained from triple superphosphate and sodium hydrogen phosphate; it is too early to say whether they are likely to be as durable as those from single superphosphate.

No significant residual effect has been obtained from any of the applications of sulphate of ammonia used in this series of experiments. The effect of gypsum applied as a dust at Kontagora in 1948 (Table 8) is, however, still persistent in respect of haulm production. Yields of kernels and haulms (lb./acre) have been:

	Kernels		*Haulms*	
	No gypsum	*Gypsum*	*No gypsum*	*Gypsum*
1948	678	+107 (15·8%) sig. 1%	1,154	+249 (21·6%) sig. 1%
1949	459	+69 (15·0%) ,,	1,728	+328 (18·5%) ,,
1950	532	+33 (6·2%) not sig.	1,095	+125 (11·4%) ,,

Placement

From the lasting residual effects that have been obtained it is obvious that on the sandy soils of the groundnut areas there is no need to use placement technique to overcome phosphate fixation. The aim of placement trials has been to ensure that the farmer shall obtain the maximum effect from the small quantities of fertilizer which he can afford; that he shall apply them, without causing damage to seed or seedlings, in a manner as closely allied as possible to his own method of planting. A secondary consideration has been the preparation and packing of fertilizers in a standard form which will protect the illiterate farmer from adulteration or depredation on the part of distributors [8].

The concept of placement is not foreign to local practice, in which the scanty supplies of organic manures are often ringed round individual seedlings. Placement has, too, been made routine in mixed farming [4]: the trickle of pen manure represented by applications of 1–3 t. per acre is laid in a thin line in the old furrows and covered by splitting the old ridges to form the new planting-ridges. It has therefore not been considered necessary to demonstrate the obvious advantages of placement over broadcasting.

Groundnuts are planted on prepared ridges by scuffling a hole with the toe, dropping the seed, sweeping back the earth with the side of the foot, and treading down by the heel in progress to the next planting-hole. When they are planted on the flat or on consolidated old grain ridges a hoe-cut takes the place of the scuffle with the toe. It was assumed that the most readily acceptable method of placement would consist in dropping fertilizer into the open planting-hole before or after the seed.

Random dropping of powders into the planting-hole could not be recommended. Groundnuts are sensitive to contact even with single superphosphate and it was found that the stand-dosage (1·2 gm.) corresponding to an application of 50 lb. per acre caused a notable germination lag unless it were distributed over a larger area than that represented by the average hoe-cut. Experiments were therefore made early in 1947 with soil/fertilizer mixtures in the hope that the farmer could be persuaded to mix one measure of fertilizer with a specified number of measures of soil and drop the mixture into his planting-holes by means of a standard scoop. This method promised no practical application as the bulk represented by a safe fertilizer/soil mixture approached that of an equivalent amount of pen manure, which in practice has been found to travel relatively short distances from the homestead. A soil:fertilizer ratio of 50:1 was needed for an application of 50 lb. single superphosphate per acre; a ratio of 300:1 was not high enough to obviate the damage caused by a 25 lb. application of sulphate of ammonia.

At the instigation of the Groundnut Mission experiments were begun in 1947 with various types of phosphatic manures made into pills representing the stand-dosage at 9 and 18 lb. P_2O_5 per acre. They were continued in 1948 and 1949 with stamped pellets of pharmaceutical type equivalent to 11 lb. P_2O_5 per acre. Although direct contact between pellet and seed was fatal with soluble phosphates (triple super, mon-

ammonium phosphate) and led to impaired growth with single superphosphate (Plate 8, Fig. 8), it was found that a lateral separation of ½ in. between seed and any kind of pellet was perfectly safe. This separation was not normally obtained by random dropping of seed and pellet, which led to a significant depression of germination of the order of 10 per cent.; it could, however, readily be achieved by covering the pellet with a little earth, pressing slightly downwards and forwards by the ball of the heel, and then dropping the seed into the resultant heel-mark. This method was given extensive trial by farmers in 1948 and 1949 and was the subject of experiments which showed it to be as effective as accurate placement of pellets at various distances from the seed and as effective as hole or line placement of powders [8].

It had originally been intended to issue phosphate in pellet form under the Fertilizer Distribution Scheme. £8 per ton had been suggested to the Groundnut Mission as the likely cost of pelleting and special packing, and this had been accepted as a reasonable charge to pay for the advantages in distribution and application which would be derived from pellets during the initial stages of fertilizer introduction. The lowest tender received by the Production Board for the pelleting of 5,000 t. of single superphosphate was, however, £20 per ton, a price which effectively put pelleted fertilizers out of the farmers' reach.

Experiments were then undertaken to find whether granules of similar weight to the pellets could be prepared at an economic rate by modification of the normal granulation process. Granules of this size proved difficult to manufacture, but it was possible to supply 1,000 t. of oversize granules, with a mean weight roughly one-third that of the stand-dosage, for distribution to farmers in 1950. Farmers had no difficulty in picking up at one pinch the three granules required per stand and dropping them slightly to one side of the seed. Again random dropping could not be recommended, for although lateral contact between one granule and seed was found to cause no damage (Plate 8, Fig. 8) the random dropping of three granules and two seeds reduced germination by 14 per cent. (mean figure for 7 sites). From the farms there were only few reports of damage due to faulty placement; the oversize granules proved very popular and are now being bought in many of the areas which received free supplies in 1950.

New areas are being supplied in 1951 with granules of normal commercial size. This change has again been dictated by considerations of cost. Oversize granules have cost about £4 per ton more than granules of normal size and it has been thought advisable to face a possible fall in oilseed prices by keeping the cost of fertilizers as low as possible. The use of material of standard particle size is also advisable in view of the present uncertainty as to which country, if any, can supply Nigerian requirements.

Preliminary experiments with normal granules of single superphosphate, applied to the planting-hole by means of a standard scoop, were made in 1950. The granules gave increased yields not significantly different from those given by pellets or oversized granules; when placed to the side of uncovered seed they caused no damage comparable to that

caused by powder, which tends to scatter over the seed or be brought into contact with it during earthing-over (Plate 8, Fig. 7).

It was proposed to supply a double-ended spoon with each bag of granules; one end to deliver 1·4 gm. (groundnut), the other 5·6 gm. (sorghum). The present scarcity of metals has led to the issue of simple bowls of these two sizes. The bowl has a lip which allows it to be inserted into a piece of sorghum stalk that forms an excellent light handle. With a handle of fair length very accurate placement is possible without bending, provided that one person is dropping the seed and a second applying the fertilizer. When one person is carrying both fertilizer and seed in a double container a long stick becomes an encumbrance, and exponents of this method have preferred as short a handle as possible, or none at all. There is little aversion to stooping even by the oldest farmers, and it seems not improbable that after short trial the farmer will pick up between fingers and thumb a quantity of granules fairly close to the correct dosage, and that scoops will find some place in the household economy undreamed of by their designers.

Summary

In view of the ready response of Northern Nigerian soils to small applications of superphosphate the Oilseeds Mission of 1947 recommended the issue of phosphatic fertilizers to groundnut farmers. They stressed the need for placement trials to ensure maximum effect from small dressings; for comparative trials of superphosphate and the more concentrated phosphatic fertilizers which offered economy in transport; for experiments with nitrogenous fertilizers and with gypsum.

An account is given of field experiments made with groundnuts between 1947 and 1950. They have shown that:

1. Pellets or granules of various phosphates can be safely placed with groundnut seed provided that there is a lateral separation of ½ in. between seed and fertilizer.

2. Highly economic returns can be expected in the year of application from the use of 11 lb. P_2O_5 per acre. Notable long-term residual effects have been obtained from single superphosphate.

3. Single superphosphate has proved more efficient than other types of phosphate, particularly in haulm production. Its superiority has been shown to be due to its content of gypsum.

4. On some soils gypsum has a direct effect on both kernel and haulm production; on others its effect arises only by interaction with phosphate. The possibility of sulphur deficiency is being investigated.

5. Nitrogen supplied as monammonium phosphate has a stimulatory effect on seedling growth; it has given no significant increases in kernel or haulm yields. Sulphate of ammonia has an effect similar to that of gypsum.

FIG. 1. Kontagora, 1948. Direct effect of gypsum. Main plot treatment = no manure. Right half dusted with 100 lb. gypsum per acre at 60 days

FIG. 2. As above. Main plot treatment = 24 lb. triple super per acre

FIG. 3. Samaru, 1949. Interaction of gypsum and phosphate. Left = 40 lb. sod. dihydrogen phosphate. Centre = no manure. Right = 40 lb. sod. dihydrogen phosphate + 50 lb. gypsum per acre

FIG. 4. Samaru, 1949. Interaction of phosphate with gypsum and sulphate of ammonia

FIG. 5. Samaru, 1949. Direct effect of phosphate on kernel and root development in contrast to negative effects of gypsum and sulphate of ammonia

FIG. 6. Samaru, 1949. Relative effects of 100 lb. gypsum (right) and 43 lb. slaked lime (right centre) dusted on plants receiving 24 lb. triple super (left centre)

FIG. 7. Effect of contact between seed and 1.4 gm. small granules of single superphosphate. Left side, placement by scoop. Left centre, random dropping. Right centre, seed dropped on top of granules. Right, granules ringed round seed in circle of 1″ radius (at 30 days)

FIG. 8. Effect of lateral contact between seed and superphosphate pellets of various weights. Left, 1.4 gm., centre, 0.7 gm., right, 0.47 gm. Left-hand member of pair in contact: right-hand placed 1″ from pellet (at 16 days)

FIG. 9. Samaru, 1948. Residual effect from superphosphate applied to sorghum in 1947. Plants represent marginal rows showing (1947) nitrogen deficiency induced by live hedge of *Commiphora Kerstingii*

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PROGENY TRIALS WITH CACAO IN THE GOLD COAST

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THE improvement of most orchard crops has been achieved by vegetative propagation of selected seedlings, resulting in clones such as the standard varieties familiar to fruit-growers in temperate regions, the citrus varieties, and the D.J.R. and R.R.I. rubber clones. Work along these traditional lines with cacao has led to the I.C.S. clones in Trinidad, and the cacao estates of South and Central America are now following suit. In these territories the cacao consists of a heterogeneous population of Trinitario seedlings, which affords wide scope for selection. Yields per acre can be trebled on estates by the use of material propagated vegetatively from high-yielding trees.

In the Gold Coast and Nigeria the cacao industries have been developed by peasant farmers, using a uniform type which was introduced originally from the Lower Amazon region of Brazil, and is now known as 'West African Amelonado'. Individual farms are usually small (less than 5 acres) and they have been established by sowing seed at an irregular close spacing with subsequent thinning. West [1] has shown that close spacing produces high yields in the early years of bearing, and it also simplifies establishment by providing mutual shade for the cacao and suppressing weed competition. In these circumstances the production of rooted cuttings for issue to the peasant farmers is not at present an economic proposition, and if the high yields obtained from clones could be attained by seedling varieties there is little doubt that the latter would be preferred.

'Clonal' seed is the only practicable form of plant improvement under these conditions, in spite of the inevitable slowness of plant-breeding with a crop which normally takes five years to come into bearing. The development of satisfactory clonal seed is more complicated than the development of a good clone. The success of the latter depends solely on the selection of a tree with the right genetical factors for crop production. For producing satisfactory clonal seed the selected clones must possess the ability to breed nearly true to type for a wide range of characters which in cacao should include yield, vigour, resistance to pests and diseases, and the numerous bean characters that influence quality.

Cheesman [2] has pointed out that the Trinitario type of cacao includes a wide range of genetical types and the most productive individual trees known, but owing to great tree-to-tree variability, it is most unlikely that the progeny of high-yielding trees will attain the standard of their parents. The early progeny tests in Trinidad supported this view, but unfortunately little reliance can be placed on these experiments because self-incompatibility, the prevalence of cross-pollination, and the necessity

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for hand-pollination were not appreciated. Before those reported in this paper, the only progeny trials with cacao using controlled pollinated seed known to the writer are those laid down by Voelcker [3] in Nigeria and by Wellensiek [4] in Java. A comparatively limited range of material was available in Nigeria, yet Voelcker's trials, which were concerned with cacao more variable than the Amelonado generally grown on West African farms, showed conclusively that bean-size can be improved by the use of clonal seed [1].

The first hand-pollination of cacao on the Gold Coast was done in 1938, and the first progeny trial with controlled pollinated seed was planted in 1939–40. Ten years later it can be said that clonal seed is practicable with cacao. The stage has now been reached when selection can be carried into the second generation, and when tested clonal seed of the first generation can be distributed. As the work continues, better clonal seed should be available every few years.

The First Progeny Trial

The methods and criteria used in the selection of high-yielding parent trees have already been described [5] and this paper is concerned with the yields of their progeny produced by self-pollination. Voelcker [6] found no difference in vigour between seedlings produced by self-pollination and those obtained by cross-pollination. In the first progeny trials, the seedling progeny of 28 West African Amelonado clones and of 2 clones of doubtful antecedents were compared. The layout was originally planned to include 192 seedlings from each clone arranged in 64 randomized plots each of 3 trees. An establishment trial [7] was superimposed in which the experimental unit was $\frac{1}{4}$-acre, and in order to ensure that the progenies were equally affected by the treatments, each $\frac{1}{4}$-acre plot contained 3 seedlings of each clone. Because of unsuitable soil and the failure of one establishment treatment [8], the number of plots has been reduced from 64 to 44, containing 132 seedlings of each clone.

The self-pollinated seed was germinated in baskets, in which the seedlings were kept until planting-time. Owing to the difficulties of obtaining sufficient hand-pollinated seed simultaneously from 30 scattered trees, and to the replacement of losses in establishment, planting was spread over three years, 1939–41, resulting in increased variation in the yields during the early years of bearing. Records have been taken of the number of pods matured by each tree. The weight of wet beans per pod was recorded in 1947 and 1948, so that the total weight of beans produced by each progeny could be calculated.

Results.—Table 1 gives the accumulated yield of the progenies since they commenced bearing up to the end of the 1948–9 crop. The two non-Amelonado progenies E1 and N38 gave the highest number of bearing trees and the highest weight of beans per pod (pod-value). Although planted in 1941, one or two years after the other progenies, E1 also produced the most pods and was by far the greatest producer of beans. N38 was surpassed in total production by the two Amelonado progenies P49 and S84, in spite of their lower pod-value. The

uniformity of the Amelonado progenies is illustrated by the little variation in weight of beans per pod, 3·2–3·6 oz.

TABLE 1. *First Progeny Trial Yields Accumulated up to 1948–9 Progenies in Order of Total Yield of Cacao*

Progeny	*No. of surviving trees**	*No. of bearing trees*	*Total no. of pods*	*Mean weight wet beans/pod oz.*	*Total weight wet beans oz.*
E1	116	84	2,325	4·2	9,765
P49	115	49	1,793	3·6	6,455
S84	114	47	1,749	3·4	5,947
N38	118	75	1,486	4·0	5,944
S72	113	64	1,562	3·2	4,998
A196	118	63	1,339	3·3	4,419
P315	112	56	1,336	3·3	4,409
A220	111	59	1,234	3·4	4,196
A20	108	58	1,233	3·4	4,192
S115	95	47	1,209	3·4	4,111
S132	106	50	1,217	3·3	4,016
P37	112	64	1,135	3·5	3,973
A187	106	53	1,219	3·2	3,900
S5	98	50	1,094	3·5	3,829
P27	112	54	1,108	3·4	3,767
P39	108	60	1,021	3·5	3,574
A164	93	50	1,025	3·4	3,485
P58	103	52	996	3·3	3,287
P512	106	51	954	3·3	3,148
P139	94	43	948	3·3	3,128
S53	110	52	913	3·4	3,104
S45	102	55	859	3·4	2,921
A121	92	52	845	3·4	2,873
P46	102	51	775	3·5	2,713
A218	91	41	640	3·5	2,240
A176	112	43	681	3·2	2,179
P710	102	45	625	3·4	2,125
A263	104	41	552	3·5	1,932

* i.e. number surviving out of the 132 seedlings planted in 1939–41.

Visual observations suggested that the progenies were behaving differently under different environmental conditions. In some plots poor soil conditions and repeated capsid damage had retarded the growth of most of the seedlings, whilst in other plots growth had been uniformly good. To find out whether some progenies had tolerated these adverse conditions better than others, the plots were treated statistically in two groups, one of 19 'Good Plots' in which more than 40 trees were bearing in 1948 with a total yield of over 500 pods, and the other of 25 'Bad Plots' which failed to reach this standard. The figure used for analysis was the total number of pods produced by each progeny in each plot, because the primary object of the trial was the comparison of the progeny performances, rather than the yield of individual seedlings.

Statistical advice was taken and because of the nature of the data, the $\log(2n+1)$ transformation [9] was applied before analysis. In Table 2 the progenies are arranged in order of merit on the basis of pod production

after this logarithmic transformation. It will be noted that this figure is not always proportional to the number of pods per tree, if only those seedlings planted in 1939–41 are considered, because some died, but it seemed advisable to take into account this factor of hardiness in establishment. Furthermore, it must be remembered that the non-Amelonado progenies, E1 and N38, had a higher weight of beans per pod (4·2 and 4·0 oz.) than the Amelonado (3·2–3·6 oz.).

On good plots E1 is outstandingly the best yielder. It is significantly better than all but five other progenies in the number of pods produced, and owing to its higher weight of cacao per pod it is very much better than all other progenies in yield of beans.

On bad plots E1 also produced more cacao than all other progenies, but it is closely followed by N38, which actually was better than E1 when the log $(2n+1)$ transformation was applied to the number of pods. E1 and N38 produced significantly more pods than all except one of the Amelonado progenies.

TABLE 2. *Comparison of Progeny Yields on Good and Bad Plots**

Good plots				*Bad plots*			
Progeny	*Weight wet beans (oz.) per tree*	*Mean pods per plot (n)*	*Mean log (2n+1)*	*Progeny*	*Weight wet beans (oz.) per tree*	*Mean pods per plot (n)*	*Mean log (2n+1)*
E1	135·2	93·2	2·199	N38	29·0	19·1	1·116
S84	96·5	80·7	1·955	E1	38·2	22·2	1·058
S72	78·0	69·3	1·861	P37	9·2	6·2	0·801
P49	117·2	90·8	1·844	A196	9·6	7·8	0·745
A196	74·0	60·2	1·804	P46	9·6	6·0	0·714
P58	58·2	49·2	1·799	A220	9·3	6·4	0·693
A220	70·2	56·5	1·724	S53	10·0	7·1	0·677
N38	77·5	53·1	1·705	A20	17·6	11·6	0·672
A187	68·4	56·2	1·704	P39	7·1	4·4	0·627
A20	70·2	49·6	1·691	S72	13·3	9·8	0·619
S5	75·3	49·8	1·685	P27	9·5	6·8	0·595
P315	75·0	63·4	1·674	S115	9·9	5·7	0·582
P27	62·5	49·4	1·641	S45	7·6	4·7	0·582
S45	51·4	39·0	1·627	A187	8·6	6·0	0·565
P512	53·5	45·3	1·596	S84	12·2	8·6	0·548
P37	64·7	51·6	1·581	S132	15·1	10·0	0·546
P39	60·1	47·9	1·573	P710	9·7	6·5	0·542
A121	53·2	38·7	1·572	P315	7·4	5·3	0·536
S132	62·5	50·8	1·538	A121	8·3	4·4	0·480
A139	60·2	45·2	1·533	S5	9·6	5·9	0·447
S115	78·9	56·2	1·532	A263	5·7	3·7	0·434
A164	67·8	49·3	1·528	P512	5·9	3·8	0·425
P46	46·5	32·8	1·415	P49	3·9	2·7	0·388
A218	45·7	29·5	1·324	A176	4·1	3·0	0·388
A176	36·6	31·9	1·319	A164	6·5	3·5	0·383
S53	50·0	38·7	1·252	P58	4·1	2·5	0·374
P710	35·0	24·4	1·227	A218	5·8	3·2	0·358
A263	34·2	24·2	1·197	A139	6·3	3·6	0·324
Significant difference = 0·412 (P = 0·05)				Significant difference = 0·350 (P = 0·05)			

* Good plots with more than 40 trees in bearing and more than 500 pods yield. Bad plots with less than 40 trees in bearing or less than 500 pods yield.

The parent trees.—When discovered in 1940, the tree E1 was carrying an exceptionally heavy crop and the pods were much larger than those on the surrounding trees, which were all of the ordinary Amelonado type. The pods of E1 approximate to the shape known as 'Cundeamor'

and are unpigmented. Bean-weights gave a pod-value of 6 pods per lb. of dry cacao (mean: 42 beans, 5·80 oz. wet weight). Selfed pods were obtained by hand-pollination in 1940, and budwood had been collected before the tree became infected with swollen shoot disease in 1941.

The seedling progeny of E1 includes a range of pods intermediate between those of the parent tree and those of Amelonado, and it seems probable that E1 is itself a natural hybrid between a Trinitario and an Amelonado tree. The tree E1 was fully self-compatible, but of 80 seedlings tested 21 are self-incompatible, a fact indicative of Trinitario ancestry.[1]

The clone N38 is the same as the Nigerian T38, a tree selected by Voelcker [3] from a plot of near-Amelonado cacao at Ibadan. The ancestry of this tree is in doubt, but like E1 it probably contains some Trinitario genes; the seedling progeny is variable not only in pod-size but in vegetative characters, a proportion of the seedlings having narrower leaves and a denser branching habit than Amelonado cacao.

The Second Progeny Trial

The Second Progeny Trial was designed to compare the yields of the progeny of 1 Amelonado and 35 Trinitario clones. These clones were developed either from trees which were growing on Agricultural Experiment Stations and which were the progeny of trees at River Estate, Trinidad, or from trees growing on African-owned farms [5]. The latter trees were also probably descendants of the River Estate trees.

The Second Progeny Trial was planted in 1942 and 1943; 72 seedlings of each clone (self-pollinated) were randomized in 8 plots of 9 trees each, so that there were 8 blocks each containing 1 plot of each of the 36 progenies. There is considerable soil variation in this experiment and the plants were retarded by capsid damage. The results (Table 3) up to the 1949–50 season confirm the early bearing habit and relatively high yield of the E1 progeny in the First Progeny Trial, and indicate that certain Trinitario clones, notably TF1, may have even higher yielding progeny.

The full analysis of genetical segregation must wait for a larger number of seedlings to come into bearing, but it is of great interest that certain of the Trinitario selections have bred true to type, not only for such characters as pod-size and shape, but also for characters which are difficult to define, such as leaf-texture and growth-habit. The uniformity of certain progeny shows that the development of clonal seed is practicable even within the highly variable Trinitario type of cacao. In this connexion it is interesting to find a positive correlation between the mean pod-size of the progeny and that of the parent clone. Weights of beans per pod were taken in 1948 for 11 of these Trinitario clones from budded trees of an age and size comparable with that of their seedling progeny. As shown in Table 4, the clones with large pods produced seedlings with large pods, the correlation being significant at the 1 per cent. point.

[1] This segregation of the selfed progeny of a self-compatible tree into 3 self-compatible : 1 self-incompatible is of interest because the genetics of incompatibility in cacao has not been investigated.

TABLE 3. *The Eleven Progenies which gave significantly Higher Yields than the Rest in the Second Progeny Trial*

Progeny parent	Bearing trees*	No. pods 1948–50	Weight wet beans	
			oz.	log (2n+1)
TF1 . .	45	636	3093·47	12·710
E1 . .	49	705	3325·98	12·601
B2 . .	36	605	2093·90	11·235
TF2 . .	34	491	2398·26	10·410
K5 . .	26	536	1851·49	10·389
U11 . .	30	546	2448·48	10·382
S36 . .	34	405	2158·59	10·355
A45 . .	30	504	1315·38	10·249
U5 . .	32	523	2128·50	9·648
E9 . .	17	321	1541·97	9·542
A12 . .	28	434	1650·02	9·284

Sig. diff. (P = 0·05) = 3·617

* Trees bearing in 1950 out of 72 planted 1942–3.

TABLE 4. *Comparison between Clones and their Seedling Progeny as regards Weight of Beans per Pod in 1948*

Clone no.	Wet weight of beans per pod (oz.)		
	Budded	Seedlings	
TF2 . .	6·0	4·9	
TF1 . .	5·4	4·7	$r = 0·8075$
R9 . .	5·3	4·3	Sig. at $p = 0·01$
SC1 . .	4·4	4·1	
A12 . .	4·1	3·5	
A62 . .	4·1	3·4	
A36 . .	4·0	2·4	
A72 . .	3·9	3·3	
B1 . .	3·7	3·8	
Y44 . .	3·2	3·1	
B2 . .	2·8	3·2	

New Introductions

In 1943 the writer went to Trinidad to select types of cacao not represented in West Africa and to dispatch seed by air to the Gold Coast. Quarantine precautions were taken in Accra [10]. As the primary object was to obtain as wide a range of genotypes as possible for resistance trials with cacao viruses and capsids, seed was introduced and not vegetative material. It was soon realized, however, that the high degree of cross-pollination in Trinidad [11] might result in the masking of any recessive genes for resistance if the pods sent from resistant trees were the result of cross-pollination with susceptible trees. Controlled pollination was therefore carried out and about one-third of the progenies now at Tafo are legitimate.

A block of 10 acres, as uniform as could be found at Tafo [12], was cleared of cacao and shade trees in 1944, planted with nurse crops early in 1945, and the cacao seedlings transplanted from pots in June 1945. The number of seedlings in each progeny was insufficient for a fully replicated layout, but two plots, one of 16 seedlings (4×4 square) and the other of 8 seedlings, were planted with most of the progenies. The trial was arranged so that these two plots were widely separated and so that each was near to one of the twenty 16-tree plots of local Amelonado seedlings included for comparison. The plants were spaced 14 ft. apart to allow the full development of the natural habit of each tree.

In Table 5 the progenies have been grouped according to their probable origins. Those called 'Upper Amazon' were the progeny of types collected by Pound [13] from the Iquitos, Nanay, Morona, Parinari, and Scavina regions of Ecuador. The 'Lower Amazons' were represented by the wild type collected by Myers [14] in the forests of Surinam and a Maranhao type from Bahia but originally introduced from the Lower Amazon region. The 'Upper Amazon×Trinitario' group consisted partly of the progeny produced by hand-pollination between the types, and partly of open-pollinated progeny (from Upper Amazon trees growing near Trinitario trees) which showed the red-pod character of the Trinitario parent. The 'Ecuador' group was heterogeneous, consisting of various types collected by Pound from estates in Ecuador; their ancestry probably included both Trinitario and Upper Amazon. The Criollo group covered a range of cacao with white beans, originating from Nicaragua, Venezuela, and Trinidad. The Trinitario group consisted mainly of the progeny of I.C.S. clones 70, 80, 91, 95.

As a group, the Upper Amazon types were earlier to come into bearing, higher yielding, and much more vigorous than other types. Only an indication of their greater vigour is given by the stem-diameter measurements in Table 5. The best of these progenies (T.63) was a result of crossing a Nanay and a Parinari type; at 4 years old every seedling had come into bearing with an average yield of 14·6 pods per tree (3·83 oz. wet beans per pod), and at 5 years old they yielded 38 pods per tree.

The only progeny approaching the Upper Amazons in yield and vigour was one from Costa Rica (T9). Figures for this progeny are shown separately in Table 5 under Trinitario to which type it may belong, although in yield and vigour it compares favourably with the average Upper Amazon. This progeny is unusually uniform for a Trinitario, and most of the seedlings resemble the United Fruit Company's clone 613 of which they are probably second-generation progeny.

In spite of the vigour and high yield of their I.C.S. clonal parents, the Trinitario progenies were less vigorous and later bearing than even the Criollos; however, the parents of the latter include such comparatively vigorous clones as I.C.S. 45, 60, and 85.

To those unfamiliar with the West African crop, the position of the West African Amelonado type at the bottom of the Table may come as a surprise. These Amelonado seedlings were the progeny mainly of high-yielding and apparently vigorous trees on the Aburi and Tafo

Stations, yet they were poorer in vigour and later coming into bearing than any other group included in this trial.

TABLE 5. *Performance of Main Types in the New Introductions in 1949–50 (Seed planted 1944)*

Group	*No. trees growing*	*No. trees bearing 1950*	*Pods per tree 1949–50*	*Wet weight beans/pod (oz.)*	*Mean stem diameter 1948 (cm.)*
Upper Amazon	527	475	17·35	3·69	6·44
Upper Amazon × Trinitario	209	166	10·25	3·64	5·70
Lower Amazon	32	27	8·62	3·79	5·95
Ecuador	273	89	2·81	3·71	5·07
Criollo	197	47	1·99	3·80	4·72
Trinitario	267	49	1·04	3·65	4·66
T9	18	18	21·25	3·58	7·75
W. A. Amelonado	229	50	1·13	3·50	3·90

Discussion

This paper summarizes the results of the first 12 years' work on the improvement of cacao-planting material in the Gold Coast. Although the oldest trees in the progeny trials are now only 10 years old, it is possible to draw some general conclusions.

During these 12 years the cacao industry in the Gold Coast has changed considerably. The devastation caused by swollen shoot disease [15] and the high price of cacao in the post-war years have created a great demand for seed. Experience gained so far with experimental replanting has emphasized the need for early bearing cacao, so that an economic return can be obtained quickly to offset the loss of the previous crop. Moreover, the control of swollen shoot depends on the prompt removal of infected trees to eliminate spread within the crop and thus to confine losses to trees which become infected from outside sources, such as wild hosts [16]. Viruses will probably continue to invade cacao farms where the disease is endemic, causing a slow but progressive loss of trees with increasing age. Pending the development of resistant cacao [17] this loss would be mitigated economically if the cropping of trees were to commence at 3 or 4 years old, instead of 5 or 6, and to give high yields in their early years. Even if these trees fail to reach as high an annual yield as later maturing trees after 20 years, they would still be more desirable for the special conditions in West Africa. The results of clonal trials in Trinidad suggest, however, that trees which give relatively high yields in their early years maintain their superiority in later years [18].

Most of the best forest soils in the Gold Coast suitable for cacao have now been used, and whilst replanting after cacao has been killed by swollen shoot is practicable on granitic soils [19], provided that the soil has not been exhausted by food-farming [20], soil conditions are not as favourable for the establishment of cacao as those found immediately after forest has been cleared. Although the Amelonado type of cacao was established without difficulty on forest soils during the rapid

development of the cacao industry between 1900 and 1920, a more vigorous type of cacao is required for present-day conditions.

The progeny trials at Tafo have dispelled the myth that the West African Amelonado is a hardy, high-yielding type ideally suited to the country; earlier selection work had suggested a similar conclusion [5]. In comparison with the best Amelonado material available, two other progenies of different origins have proved more vigorous and earlier bearing, a superiority which was accentuated by poor soil conditions and capsid attack. As the E1 progeny proved better than the N38 progeny in a comparatively good environment and equalled it under bad conditions, the E1 progeny seems to be the better choice for distribution as clonal seed, although the N38 progeny may prove valuable for marginal areas. Cropping on a mono-clonal plot of E1 has started at the Cocoa Station of the Department of Agriculture, and further propagation of clonal E1 is in progress for the production of clonal seed.

The second Progeny Trial showed that the E1 progeny can hold its own against the best Trinitario material available in West Africa prior to the 1944 introductions, and it is unfortunate that no direct comparison is yet possible between the latter and the E1 progeny. The Upper Amazon types are so much more vigorous and higher yielding than the Trinitario, Criollo, and Amelonado types in the New Introductions Trial, however, that there is little doubt that they are the most useful material for selection. Provided that the commercial quality of their beans is acceptable to the trade—and this is not yet known—these Upper Amazon types would provide the best seed now available to fill the immediate demand.

The Upper Amazon types have one obvious disadvantage. Each tree is sterile with its own pollen. This self-incompatibility differs from that in Trinitario cacao in which self-incompatible trees are also incompatible with each other's pollen [21]; among the Upper Amazon trees there is a high degree of compatibility between self-incompatible trees [22]. Efficient cross-pollinating insects are present in the Gold Coast [23] and the results of the Introductions Trial confirm that high yields can be obtained from a mixed planting of Upper Amazon seedlings. For more extensive trials, seeds of the Upper Amazon types have been issued to the Agricultural Departments of the Gold Coast and Nigeria for tests under a wide range of conditions.

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Summary

Progeny trials of high-yielding cacao selections were planted between 1940 and 1943, using self-pollinated seed. The progeny of one Trinitario selection, E1, proved to be superior in yield and bean-size to all Amelonado selections tested; on poor soil it was equalled by another selection from Nigeria, N38, which is probably partly Trinitario.

In another progeny trial, the E1 progeny yielded more cacao than all other selections, but was slightly inferior to another Trinitario progeny when the log $(2n+1)$ transformation was applied to the individual tree yields.

There was a positive correlation between the pod-weights of Trinitario clones and of their seedling progeny.

A collection of various types of cacao was introduced to the Gold Coast from Trinidad in 1944. The Upper Amazon types were more vigorous, earlier bearing, and higher yielding than the Lower Amazon, Criollo, Ecuador, Trinitario, and West African Amelonado types. The best Upper Amazon progeny, a Nanay × Parinari cross, gave a mean of 38 pods per tree at 5 years old, compared with 1·2 pods per tree for Amelonado seedlings in the same trial.

The use of clonal seed in the replanting of cacao areas devastated by virus diseases is discussed in relation to these results.

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TECHNICAL CONSIDERATIONS IN THE ECONOMIC DEVELOPMENT OF SUKUMALAND

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WITH PLATES 9, 10, 11

Agricultural Conditions

SUKUMALAND borders the south coast of Lake Victoria, and consequently the continental climate is slightly altered by the lake. The altitude above sea-level varies from 3,700 to 4,000 ft. The rainy season extending from November to May may have a gap about February, but the short rains favour planting and the long rains induce growth and maturation. Two crops cannot be obtained. The appearance of the country in the dry season is semi-arid. Temperatures are equable with a mean maximum of about 84° and a mean minimum of about 63° F. Rainfall is the greatest hazard; it varies from 25 to 45 in., decreasing to the south and east.

The original vegetation varies from thorn on the lower-lying lands and on all land to the east to open woodland and Brachystegia or Combretum on the hill-sides and hill-tops, and particularly to the west. Granite is the principal underlying rock. There are no permanent rivers. Water is obtained principally from sandy river-beds, river-pools, seepage-areas and ponds, and artificially by impounding water behind earth-dams and in earth-tanks. The appearance of the country is that of a treeless plateau, broken by rocky kopjes and interspersed with wide valleys or vast plains of black clay soil. The occupied area is so densely cultivated and treeless that it is often termed 'cultivation steppe'.

One million people occupy 9,000 square miles of country. As they spread out into the relatively fertile bush on the perimeter of occupation they bare the country of trees and grass. They clear-fell for cultivation, because trees harbour tsetse-fly, vermin, and birds (Plate 9, *b*). The large herds of cattle leave little shelter for ticks, and thus assist in reducing the incidence of tick-borne diseases. The uncontrolled movement of people and stock combined with the usual misuse of the land has resulted in soil erosion and the loss of vegetative soil cover. The soils are intrinsically fertile, mostly deep, and thus capable of rehabilitation. Where the light soils of moderate fertility predominate, they support pennisetum and cassava as the staple foods; the fertile heavy soils are planted with sorghum. Pulses and cotton will thrive on both.

Whilst the Sukuma tribe own 2 million stock-units (one stock-unit equals one bovine, or five sheep or goats), they combine cattle-keeping with agriculture, and rely on the latter for subsistence. It is their methods of stock-keeping rather than of agriculture that have resulted in the loss of so much fertility by rain and wind. They are industrious agriculturists, by no means unskilled. The tribe relies on agriculture for

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a livelihood, as only a small proportion go to the mines and other industries. The standard of living is still very low, for the time and land they can spare for cash crops is limited.

A development plan, supervised by a team of officers, and costing over £500,000, has been in operation for 3 years. By 'development' is implied the planned settlement and use of areas on the fringes of, or within, Sukumaland which are at present uninhabited or under-inhabited, and which could be settled if some obstacle, either lack of water, presence of tsetse-fly, or lack of communications, could be removed. Attention is also paid by the team to overall planning of land usage and to rehabilitation in pilot areas. Of great importance is the orderly settlement of people and stock on the land at reasonable densities. Such is the pressure on the land, however, and so considerable has been the increase in population in the last 35 years that in the future it is not expected that there will be any more land available for resting. The development plan is, therefore, another of those ameliorative measures which prevents the deterioration of a situation, but does not necessarily of itself raise the status of the land, or production per unit, above the *status quo*. New fertile land, of course, is better than worn-out land, but under primitive agriculture it will not produce the maximum of which it is capable.

The work of investigation is carried out by the Empire Cotton Growing Corporation and departmental staff of the Ukiriguru and Lubaga Experimental Stations; the task of extension is undertaken by the field staff of the Agricultural Department with the assistance of the Administration. The task under discussion is that of improving the agricultural methods in order to give a positive increase from the land, which, together with the maintenance of fertility, should enable the peasant to improve his standard of living without increasing the size of his holding. In due course all the new areas will be occupied, and population will continue to increase. How can these areas be preserved under those conditions, and with what profit and to what extent can the old areas be made to produce more and at the same time have some of their fertility built up again?

Production

Examination of the five-year running averages (Table 1) shows that the production of the main cash crops of cotton, paddy, and groundnuts is on the decline. The loss of cash through yield has, however, been more than compensated by the rise in the price per unit of produce and also by the development of other crops such as chickpea (*Cicer Arietinum*) and hand-decorticated hedge sisal. The increase in population over the past 35 years is considerable, although the early figures are of doubtful accuracy (see Table 2).

It is likely that a steady increase in population will continue. A falling output has therefore had to be divided among an increasing number of producers. The value per adult male of crops sold in 1948 was £4. 12*s*. for animal and crop products of which £2. 17*s*. was for crops which amounted to 38,682 tons, equalling only 155 kg. per adult male. It can

TABLE 1. *Production and Value of Crops and Animal Products in Sukuma*[1] *(Five-year running averages)*

Cash Crops except Cotton

Five years up to	*Groundnuts (tons)*	*Paddy (tons)*	*Grains (tons)*	*Chickpea (tons)*	*Value to grower of all produce except cotton £*
1940	4,657	5,516	..	..	..
1941	3,093	5,614	..	..	..
1942	2,691	6,615	..	..	..
1943	2,471	6,898	..	..	70,514
1944	1,771	6,353	..	..	73,424
1945	1,809	4,812	..	..	71,741
1946	1,375	3,621	..	905	63,139
1947	951	3,479	1,878	1,544	81,263
1948	1,105	3,899	2,004	1,504	107,405
1949	1,077	3,583	1,441	1,996	123,241
1950	1,048	3,954	948	2,660	133,207

Cotton and Animal Products

Five years up to	*Cotton*		*No. of cattle sold*	*Value of animal products £*	*Value to grower of all produce*
	Cotton (bales)	*Value to grower*[2] *£*			
1943	32,469	187,000	..	..	257,514[3]
1944	28,348	179,000	74,203	197,875	450,299
1945	26,911	204,000	82,322	236,775	512,516
1946	22,863	216,000	84,811	270,728	549,867
1947	21,467	208,000	82,838	310,735	599,998
1948	24,112	290,000	74,770	338,968	736,373
1949	25,961	236,000	67,230	402,989	762,230
1950	25,240	365,000	61,225	449,582	947,789

[1] Sukuma includes the districts of Mwanza, Maswa, Shinyanga, Kwimba, and Geita.

[2] An increasing proportion of the export value of cotton has, since 1943, been credited to the Agricultural Development Fund of the Territory.

[3] Excluding animal products.

TABLE 2. *Population (Census Figures)*

1913	600,000 approx. (of doubtful accuracy)
1928	729,000
1931	791,000: 31 per cent. increase on 1913
1948	1,029,926: 30 per cent. increase on 1931

be seen that output per man in terms of both weight and value of produce marketed is very low.

Turning to the agricultural-holding and man-power potential, the proportion the different crops bear to one another is shown in Table 3,

TABLE 3. *Total Acreage of Crops, Sukuma, 1945*

Crop	*Acreage to nearest thousand (000's omitted)*		
Sorghum	346	Food	695,000
Pennisetum	182		
Cassava	93		
Sweet potatoes	33		
Maize	24		
Bananas	5		
Eleusine	4		
Other legumes	4		
Sundries	4		
Groundnuts	25		
Paddy	16	Food and Cash	54,000
Cowpea	13		
Cotton	87	Cash only	87,000
	836,000		

where it will be seen that cash crops account for only 15 per cent. of the total acreage. Table 5 provides the percentage of the different soils under cultivation, and the principal crops grown on them. It should be noted that 40 per cent. of soils cultivated are heavy and suffer little, if at all, from soil erosion, so that they are unlikely to become exhausted quickly. The average acreage of crops and pasture, and head of stock per adult male, are detailed in Table 4. The average requirements of

TABLE 4. *Average Areas under Arable Crops and Pasture and Head of Stock per Adult Male*

Total population, 1948	1,029,926
Adult males, 1948	250,242
Total stock-units, 1948	1,969,818
Total area approx.	5,760,000 acres
Total arable, 1945	835,276 acres
Average acreage arable per adult male	3·34 acres
Average acreage arable per head	0·81 acres
Approximate gross acreage, pasture	4,924,724 acres
Average acreage pasture per adult male	20·00 acres
Average acreage pasture per stock-unit	2·5 acres
Approximate no. of homesteads	125,700

grain and cassava flour of the average family of seven is 2 tons, which allows a little for the making of beer (Pl. 10, *a*). In the very dry famine year 1949, when four of the five districts of Sukumaland had to be provided with 18,000 t. of food, a survey of crop-yield was made with results given in Table 6.

TABLE 5. *Percentage of Different Soils under Cultivation in Sukuma*

District	*Total acreage*	*Light soils*				*Heavy soils*				
		Kikungu	*Isanga*	*Luseni*	% *Light*	*Itogolo*	*Ibambasi*	*Mbuga*	*Ibushi*	% *Heavy*
Mwanza .	131,202	16·1	3·7	58·0	77·8	16·3	0·3	5·4	0·2	22·2
Geita .	88,130	11·8	1·6	75·0	88·4	3·0	0·4	3·0	5·2	11·6
Kwimba .	247,125	2·2	2·0	38·0	42·2	24·0	0·3	27·0	6·5	57·8
Shinyanga .	230,230	10·0	20·0	9·0	39·0	10·0	1·0	35·0	15·0	61·0
Maswa . .	144,210	20·0	1·0	14·0	35·0	22·0	2·0	25·0	16·0	65·0
Type of soil .		Red sandy	Coarse gritty sand	Fine flowery sand	Total acreage light soil 499,241 60%	Grey clay loam. Sub-soil hardpan	Hardpan	Heavy black fissuring clay	Shallow black friable loam	Total acreage heavy soil 336,759 40%
Predominant crops		Pennisetum, maize, groundnuts, cassava, sweet potatoes				Sorghum, cotton, chickpea, sweet potatoes				

TABLE 6. *Crop Yields in Sukuma (excluding Nassa) in 1949*

Crop	*No. of plots sampled*	*Yields*[1] *(lb./acre)*
Cotton (seed-cotton) . . .	714	288
Sorghum	702	470
Cassava (raw root)	247	4,602
Pennisetum	283	519
Paddy (rain-grown) . . .	63	974

[1] Weighted for size of field.

This gives an idea of the present level of yield. It is average for cotton, and thought to be low for sorghum, cassava, and paddy.

Customary Agriculture in Sukuma

The 2½-lb. hoe with a long handle is the tool in use. There are only 1,000 ox-ploughs. On the light soils, ridges 4–5 ft. from crest to crest are made, whilst on the heavier soils flat cultivation is practised. At the beginning of the rains, fields are fairly clean after stock have cleared up the residues. Weeds and residues that are left are drawn into the furrow and covered by the new ridge. It is not customary to make the ridge first and plant at an opportune time afterwards; both operations are done simultaneously. Considerations of period of maturity of the crop alone affect the time of cultivation on the light soils on higher lands. On heavy low-lying soils—of which there are magnificent stretches—crops have to go in early as the soil becomes unworkable with rain (Pl. 9, *c*). Mixed cropping is practised chiefly in pennisetum on light soils. Cassava is interplanted with pulses. Sorghum is generally pure. Maize is the best grain component in a mixture, but is not really suited to the conditions. Cotton is planted pure in two lines on a ridge, except on the medium-heavy hardpan soils, and (although rarely planted) on the low-lying clays, when flat cultivation is the rule. Chickpea is planted at the end of the rains on the water-conserving clays. The centre of Sukuma is characterized by large *mbuga* systems, where sorghum is the principal crop. These soils are very fertile, and the only problems are those connected with monoculture and weeds, including the parasitic Striga. The remainder of Sukuma has varying proportions of heavy and light soils, the latter predominating for agriculture, particularly to the north, south, and west (cf. Table 5).

Methods of Increasing Production

(*a*) *Cultivation methods on light soils.*—Of greatest importance is keeping the soil *in situ*. To do this, rain must be held (Pl. 10, *b*). Rainfall is often marginal for crops in Sukuma, so prevention of erosion by holding water in ridges, and preferably tie-ridges, actually leads to increases in yield of crops, particularly in dry years. Ridges running down hill-sides must be realigned across the slope. The practice of ridging by hand takes 168 man-hours per acre; tie-ridging takes only another 32 hours of

labour. The increase in yield resulting from building a good ridge and tying it, as compared with the characteristic poorly-made indigenous ridge, varies from year to year; it can be quite small but it can also more than double the crop (Pl. 10, *b*).

Early planting of grain and cotton is fundamental for maximum yields. A delay of 2 months may halve the crop. Early weeding is very important indeed; late or continuous weeding may even be unnecessary unless Striga is a problem.

The rotation of grain, cotton, and cassava is profitable. Particularly valuable are the rotational effects of cotton and cassava on grain, resulting in variable but substantial increases.

There is benefit to be derived from grass or pigeon-pea fallow, which may last a considerable number of years. It is thought that the ley should be repeated every 3 or 4 years. Increases of as much as 25 per cent., compared with continuous cropping, have been obtained 6 years after breaking. All these are measures that can be classed as 'good farming'; they involve very little extra work and no additional equipment.

The use of manure is rather a different matter, as this involves either head-transport or the acquisition of wheeled equipment. The effect of organic manure, such as f.y.m. or compost, is phenomenal. Not only does a dressing of 7 tons per acre result in increases of 40 per cent. to 50 per cent. in grain or seed-cotton in the first year, but an increase of 20 to 40 per cent. per annum may persist without any additional applications for as much as 5 more years. The gross return over 6 years for one operation is therefore very considerable. The economic value of this operation is unquestioned, but it is of course difficult to convince the peasant of this long-term return.

(*b*) *Cultivation methods on black loam soils.*—These friable black loams all require adequate measures for conserving soil and water. Tie-ridging fulfils this dual requirement. About 100 per cent. increase in yield results from this measure as compared with flat cultivation, of which the ridging operation itself is the most important.

(*c*) *Cultivation methods on heavy soils.*—The 'Ibambasi' hardpan, which is so little cultivated owing to its intractable and impervious nature, responds very favourably to tie-ridging. Not only does the ridging result in a 66 per cent. increase in yield, but the very operation and holding of water softens the soil so that it works more easily, thus encouraging its continuous use. The heavier, fertile, slightly alkaline low-lying clays or *mbuga* do not appear to require ridging, which is in any case a difficult operation. There is little indication so far that anything but shallow cultivation is required. This may be partly due to the cracking that provides aeration, and to its natural tilth. Manuring assists considerably in enabling a crop to yield in spite of Striga.

(*d*) *Selection and breeding.*—This work is proceeding with cotton, sorghum, and rice; rice has had little attention paid to it so far. Notable increases in cotton are recorded from Ukiriguru and Lubaga stations, supported by widely scattered district plots. UK 46 is the latest strain to be distributed. This strain may under certain circumstances give an increased yield of only 5 per cent., but in other circumstances its yield

may exceed that of the existing strain by as much as 50 per cent. The average increase might be taken as 20 per cent., though it will be appreciated that this is a very difficult figure to arrive at when considering the crop as a whole and the average of many different seasons. Its superiority to the previous strain MZ 561 is principally due to jassid-resistance, some blackarm resistance, and to its free-fruiting qualities. An increase of 1·5 per cent. in out-turn of lint on ginning has been consistently recorded, representing a profit of £1 per bale f.o.b. Mwanza, i.e. £35,000.[1] This work proceeds, and the superior UK 48 is now under multiplication. The attention of the plant-breeder is directed to the production of a short-term moderate-storing variety of sorghum. Improvement of the existing long-term varieties will later be attempted. 'Dobbs' sorghum is tolerant of Striga and its use is spreading (Pl. 11, *a*). As regards rice, a high-quality paddy of good yield, 'Kahogo', has been tested and found suitable for these conditions. Spacing of 6 in. between transplanted seedlings is advocated. Puddling-in of green material before transplanting is worth while. Selection of improved types continues.

Very considerable increases in yield of cassava root can be obtained by planting the mosaic-resistant strains isolated at the East African Agricultural Research Station, Amani. There also appear to be some varieties that yield well in spite of mosaic. Distribution of these strains should lead to an increased acreage and production of this root-crop.

(*e*) *Pasture management.*—Little is known as yet of the carrying capacity of properly managed planted pastures. The advantages of good management of natural pastures are immediately obvious. In order to manage pasture properly some de-stocking or redistribution of stock would be necessary. The statement that the individual stock-keeper would be better off with fewer well-fed cattle in good condition is indubitable, quite apart from the benefits which accrue to the land. Reservation of grazing to allow seed to ripen and fall is practised and is beneficial. Further extension of this practice is possible and desirable. Some species of grass have been tested and found suitable for this region, although little other work has been undertaken with them as yet. *Cenchrus ciliaris*, *Chloris gayana*, and *Bothriochloa insculpta* are the most promising species.

(*f*) *Assistance of the wheel and machinery.*—The rise in price of raw products has placed considerable sums of money in the hands of cultivators, and many are now in a position to consider the purchase of equipment for their small holdings. Here is an ideal opportunity, although yields are still low, to capitalize the farm before prices fall again. Equipment in the form of ploughs and better tools is required, also vehicles to carry produce, crop residues, manure, and building materials. Simple equipment to ease the tasks of the housewife is necessary to give her more time for working in the field.

The plough is needed to enable the cultivator to plant at the right time (Pl. 11, *b*). It will turn up lands in his rice fields. It will break lands

[1] Value to the territory in export value is nearer £80,000 at today's prices (January 1951).

otherwise unutilized owing to the difficulties of cultivation by hand. The tractor would enable the cultivator to operate soils in the best possible manner, for instance, hand-ridging is an impossible task on some of the hard, sloping, erodible soils of East Sukuma (Pl. 10, *c*). The pickaxe is used for breaking land for chickpea on the heavy hard clays in the dry season. Ley-farming cannot be adopted while the hand-hoe is in general use, nor can the sowing of pastures be expected. The invention of an ox-drawn ridging plough, which would make a 4-ft. ridge, would replace at least part of the arduous hand-labour required to ridge the 400,000 acres of light land for grain and cotton. This type of plough is now being evolved. At present, owing to the dangers of soil erosion, ploughing is permitted only on heavy soils, which are generally flat.

Experiments with tractors so far indicate that tractable soils may be broken for 30*s*. per acre, whilst very rough, intractable soils may cost as much as 50*s*. per acre, using a crawler tractor. Nevertheless, it is not thought that this charge will put the tractor beyond the means of the cultivator. Little is known of the physical value of deep ploughing in comparison with the shallow scraping given by the hand-hoe. Control of weeds is obviously facilitated and especially attracts the cultivator. The use of tractor-ploughs, if proved economic and practicable, is going to bring a higher proportion of heavy land under arable and thus relieve some of the pressure on the lighter soils. Moreover, those soils may be made more productive, and of wider use, because the tractor can undertake what the hand-hoe cannot do. Testing of equipment for ridging the light lands proceeds. So far as can at present be ascertained costs will not exceed 27*s*. per acre. Mechanization will give the cultivator time to practise the new improved agricultural methods which, at the moment, he claims, delay planting. It is difficult for him to understand that a small area planted well will produce as much as a larger area planted badly, and of course takes no longer time. Carts or wheelbarrows are required to carry the 5½ t. of crop-residues from the fields of each homestead to the cattle kraal and the 12 t. of manure back again to the field. The transport of loads of manure from cattle kraals to the field—3 t. at a time—by a Ferguson tractor at the economic charge of 7*s*. a load is proving very popular. An outlay of 28*s*. would, therefore, deliver his manure to the fields. If the manure was applied to cotton the transport charge would be covered by the increased yield in the first year, the remaining years of residual value leaving a clear profit.

Conditions necessary for Increasing Production

The average density of population is 111 to the square mile of occupied country, which includes some secondary bush, both on worn-out lands and on hill-tops. Densities of humans reach as high as 450 to the square mile, and of stock-units to as low as 1 acre of pasture per unit. This figure of 111 exceeds but a little what is recommended as a basis for new virgin settlements in Sukuma, but two-thirds of the area now occupied has been under constant cultivation for centuries, and has suffered thereby and cannot carry the same densities as new land. The recom-

mended figure of 100 was arrived at taking into consideration the following factors: (*a*) needs of stock; (*b*) the fundamental need of animal manure for good, permanent, non-shifting crop husbandry under these climatic conditions and with these people; (*c*) the fact that stock have to be catered for in any case. This figure allows for the holding of the existing average number of stock per adult male, under virgin conditions. In other words, existing densities on old lands will have to fall to enable pasture and arable to rest. Possibly they may later recover enough to carry this density again.

To facilitate proper management, units of land must be defined so that each may have its own management committee or council. These units for management have been named 'land-usage areas' and are self-contained for grazing, water, and agriculture. In area they vary from 20 to 200 sq. miles, and they are composed of parishes, which are the political units. Councils are to be set up in each land-usage area to organize settlement in the new areas, and to adjust it in the old. These councils may also be political. Their duties will initially involve controlling settlement and later restricting stock. They may later extend to land management in its wider sense. The development of agriculture requires to be organized from a position much nearer the peasantry than the office of a government official, and this is a step forward.

Although there is no doubt that excessive pressure on the land leads to the use of better methods of husbandry, inevitably this occurs only after it is too late. The best conditions for increased production involve a nice balance between humans and stock, which enables the best use to be made of the land. Soil-conservation measures must be practised from the beginning; grazing and forest reserves must be set aside in the first instance. There must be some pattern on the land, in the form, maybe, of strip cultivation with alternate strips of grass, grassed drainage-lines, protected hill-tops and adequate roads and paths of ingress (Pl. 11, *c*). Under these superior conditions there will be a maximum return from the crop when it is treated as recommended.

The development of new areas is an integral part of the production programme; 6,880 sq. miles are earmarked for this purpose. The worn-out light lands will produce considerably less than the yields in Table 6. Yields at the Ukiriguru station on the other hand have averaged over a number of years 600 lb. of seed-cotton and 450 lb. of pennisetum per acre. These fields were ridged well, but not manured. The crops were planted at the right time with correct spacing, and weeded early. There is no doubt that new soils properly treated are producing nearly double these yields, and will continue to produce good yields if the best methods are adopted.

Potential Production

In order to assess the probable results of applying agricultural techniques to crops in Sukuma, it is necessary to estimate the future production of an average adult male and his family. This is not an easy task, and although all the figures are based on the results of experiments that have been carried out over many seasons and on different soils, the

average return to an average cultivator in an average year must necessarily be more an intelligent guess than a matter of fact. However, there is much factual material on which to base these figures, derived from the random sample surveys (*v.* Tables 3, 6) both of which have been repeated in 1950. It is unlikely that the yields of groundnuts and chickpea will rise, so that consideration of the potential increase in production will be limited to grains, paddy, and cotton. In 1948 the average value of plant products to the adult male cultivator was 57*s.*, of which 44*s.* was cotton, from an average of two-thirds of an acre.

A tie-ridged manured cotton-field of two-thirds acre of variety UK 48 should produce at the rate of 850 lb. per acre, which at the values of 1948 would provide 134*s.* It must be remembered that residual values up to the fourth year are not so very much less than in the year of application. Three-quarters of an acre of pennisetum will yield under similar conditions 600 lb. as against 387 lb. This addition would provide twice the requirements for communal grain storage and also 19*s.* in cash. One and a quarter acres of sorghum, if spaced properly, weeded early, and kept reasonably free from Striga, will yield considerably more than at present, but the actual increase is difficult to estimate. The peasantry are being taught to level out their bunds for rice, to conserve water in communally built dams, and to plant pure varieties of good yielding capacity. Cassava varieties resistant to mosaic will raise the yield very considerably. These improvements also should lead to increases, which are difficult to estimate. There is estimated to be one surplus beast per adult male every year. This animal could be sold for at least 80*s.*[1] These figures show that the income could rise to 261*s.* (instead of 92*s.*, including value of stock sold).

TABLE 7. *Value in shillings of Produce Sold per Adult Male in 1948*

	Potential s.	*Actual* s.
⅔-acre cotton[1] (566 lb. at 24 cents allowing for 3rd quality)	134	44
100 lb. grain at 19 cents per lb.	19	13
Value other crops, 1948	13	
Value animal products, 1948, excluding livestock . .	15	15
Value one beast, 1948	80	20
	261	92

[1] Average acreage of cotton per adult male 1949.

This additional annual income should be more than enough to enable the farmer to provide himself over a period of years with equipment, such as a plough, a wheelbarrow, a muck-fork, a shovel, and pickaxe, at a total cost of 200*s.* He could afford to pay for an acre to be ploughed every year for 30*s.*, broken for 50*s.*, or ridged for 27*s.* by mechanical means, and in addition 28*s.* for the transport of all his manure. The

[1] One beast was sold for every 3·4 adult males in 1948 and for every 2·2 adult males in 1943.

increased productivity of land under food-crops should either allow some surplus land to go to rest, or provide more cash crops, as it is unlikely that grain will ever be a big cash crop in Sukuma. This will be another gain to the peasant. Collection of all residues would enable the farmer to manure an additional acreage of land to that which he cultivates at present. Alternatively, the permissible density of population could be raised to 160 people per sq. mile, provided the number of stock was reduced by half. Manuring in itself will often double straw production, and the more the straw, the more is the manure. The transport of this bulk is not possible without the use of the wheel. The introduction of carts and barrows is absolutely fundamental.

Summary and Conclusions

Important factors affecting production have been briefly discussed, and figures provided in support. There must be an assurance before developing new areas that better methods are to be adopted in order to prevent the new land deteriorating to the same extent as the country already occupied. It is accepted that there can be no real progress in East African agriculture until the work of the hand-hoe is augmented by wheeled equipment and modern implements. Do Sukuma agriculturists show any prospects of being able to provide the capital cost of such equipment, and do new methods and new strains of seed offer good prospects of a return for the money invested by the peasant? The answer is yes, principally due to the outstanding efficiency of the tie-ridge for conserving soil and water, the phenomenal recurrent returns from modest applications of manure, and the considerable success of the elementary, and by no means exhaustive, plant-breeding work that has been carried out. Are the other forms of capital fundamental to farming available for all if required? Land is held in cultivation tenure, and nobody is landless. Sixty per cent. of the homesteads keep stock, and there is no difficulty at the present time in dividing up manure among those who do not possess cattle. The number of stock is more than adequate for the production of manure; in fact, the controlling factor is crop residues rather than dung and urine. Population is steadily increasing, and new lands will eventually all be taken up. If by that time the people have not accepted the improved methods, then their standard of living must fall, for unless some check is put on the increase of population, only increasingly efficient techniques of land-usage can maintain their living standards.

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(*a*) A typical Sukuma homestead with open cattle-kraal

(*b*) Land clear-felled for cultivation

(*c*) Scraping the surface soil before dry-planting sorghum

(*a*) The average family of seven requires two tons of grain and flour

(*b*) Tie-ridged cotton on black loam

(*c*) Hand-ridging is impossible on certain soils—the tractor is needed

(*a*) Carrying home the sorghum harvest

(*b*) Ploughing, leaving a contour strip of 5 yds. of grass

(*c*) The contour grass strip to stop extension of wash in a flat cultivated field

PILOT-SCALE CROP COSTINGS ON GROUNDNUTS, SORGHUM, AND MAIZE AT URAMBO EXPERIMENTAL STATION, TANGANYIKA TERRITORY, 1949–50

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SINCE 1948, costings have been secured of the large-scale agricultural operations, over tens of thousands of acres, conducted by the Overseas Food Corporation at Kongwa and Urambo. These costings refer to the early stages of new agricultural systems, in which the European and African staff is still to a large extent incompletely trained or experienced. Consequently these costings, although of considerable internal value, do not represent even an approximate estimate of what may be expected as the systems settle down.

Agricultural research by the Corporation had by the end of 1949 largely established methods of production of various crops, particularly groundnuts, sorghum, and maize. Much of this research, before the 1949–50 season, had been concerned with small-plot experiments of standard type, and the need was felt to extend the results to costed field-scale production. For these reasons a series of costings trials was undertaken in that season at Urambo, Western Tanganyika. Of the very considerable area of costed planting there, a trial analysis has been made of 82 acres of crops, made up of roughly 32 acres of groundnuts, 26 acres of maize, and 24 acres of sorghum. Each crop was represented by separate plots, on different soil types, and worked according to sequences which varied somewhat in accordance with conditions. The methods and results of this work are reported in the present paper.

This inquiry is regarded as a preliminary study only. In the 1950–1 season work on a far larger scale is in progress to broaden and extend the validity of the present conclusions.

Methods of Crop Production

Groundnuts.—One of the groundnut plots was located on red and the three others on grey sandy soil. The variety used was Natal Common. Planting-date ranged from Dec. 15 on the red soil to Dec. 27 on the grey. Row-width was 28 in., and 50 lb. of seed were sown per acre with the Massey Harris 433 planter at a setting to give one seed every $3\frac{1}{4}$ in. One cwt. of ammonium phosphate (11 per cent. N, 48 per cent. P_2O_5) per acre was placed at the level of the seed and 2 in. to either side. Plot-sizes and cultural details varied, as shown in Table 1, but for the purposes of costing the four plots are treated together. Hand-weeding

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was used in addition to mechanical cultivation. All plots were dug with a standard Massey Harris digger and the crop was subsequently worked by hand-labour as shown in Table 5. The overall cost represents the average cost of slightly differing cultural sequences on two soil types.

TABLE 1. *Plot-size and Mechanical Cultural Operations on Pilot-costings Plots. Groundnuts, Urambo, 1949–50*

	Plot number			
	1	*2*	*3*	*4*
Size of plot (acres) . .	5·9	6·2	10·8	9·3
Soil type	Grey	Grey	Grey	Red
Implements used:				
Tandem disk-harrow .	+			
Zig-zag harrow . .		+	+	+
Lilliston weeder (16 ft.) .	+	+	+	+
Inter-row cultivator . .	+	+	+	+
Ridger	+	+	+	+

+ indicates one operation with the implement shown.

Maize.—Of the two maize plots one was located on grey and one on red soil. The variety used was Katumbili, and the plots were planted on Jan. 14 and 17, too late for high yields of this variety at Urambo. With the Massey Harris 433 planter modified for maize, 9 lb. of seed per acre were planted in 42 in. rows with 18–24 in. spacing between the plants. Ammonium phosphate was applied at 1 cwt. per acre, and placed as for groundnuts. Cultural practices again varied between the two plots, as shown in Table 2. Harvesting was by hand. The grain was subsequently threshed off the cobs mechanically. The mechanical cultural operations are specified in Table 2, hand operations in Table 5.

TABLE 2. *Plot-sizes and Mechanical Cultural Operations on Pilot-costings Plots. Maize, Urambo, 1949–50*

	Plot number	
	1	*2*
Size of plot (acres). . .	12·7	13·0
Soil type	Grey	Red
Implements used:		
Tandem disk-harrow . .	*a*	+
Lilliston weeder (16 ft.) .	+	

+ indicates one operation with the implement shown. *a* one acre only.

Mechanical work in this crop has been reduced to a very low level.

Sorghum.—The two sorghum plots were located on red soils. The variety used was Martin's Milo, the plots were drilled on Feb. 2, and 18 lb. of seed were used to the acre (on account of the low germination

of the seed, 23 per cent.) in 12 in. rows. Ammonium phosphate, 1 cwt. per acre, was broadcast immediately after planting, with a spreader, and was worked in with a Lilliston weeder. The subsequent cultural practices are shown in Table 3, and hand operations (weeding and roguing) are indicated in Table 5. The crop was harvested with a 12-ft. Massey Harris No. 26 combine.

TABLE 3. *Plot-sizes and Mechanical Cultural Operations on Pilot-costings Plots. Sorghum, Urambo, 1949–50*

	Plot number	
	1	*2*
Size of plot (acres)	13·0	10·7
Soil type	Red	Red
Implements used:		
Tandem disk-harrow	+	+
Lilliston weeder	+++	++

+ indicates one operation with the implement shown.

In all cases the land was one-way disked at the end of the previous season or immediately after the first rains. In disk-harrowing three tandem disk-harrows were used in tandem. Either three or six sections were drawn in zig-zag harrowing. The sample thus offered for analysis is of a size which would be regarded as satisfactory in costings studies in the United Kingdom.

Methods of Costing

For this sample, precise details of seed and fertilizer used, of equipment and times of operation, of hand labour and hours of work and of yields, have been secured. The computations which follow refer strictly to direct operating costs. Nothing has been included for overheads, i.e. for expenses, such as European salaries and housing of labour, which are fixed but which cannot be spread with exactitude in the present investigation over the various crops or other activities of the farm.

The costs per hour of operation taken in this study are not those realized on the experimental farm, although these costs are known. Instead, the costs of operation on production units and farms have been used. In many cases, owing to closer and more skilled supervision, the experimental farm costs are lower than those on units and farms, and their use would give an underestimate of the probable large-scale cost.

Tractors.—The cost of a tractor-hour was derived from a six months' study (April–Sept. 1950) of large-scale working at Kongwa. It is made up of 5·89*s.* running expenses plus 1·18*s.* depreciation, giving a total of 7·07*s.* per hour.

Combines.—The cost of a combine-hour was taken in the same way from production records. It is made up of 11·07*s.* running expenses plus 7·80*s.* depreciation, giving a total of 18·87*s.* per hour.

Implements.—The implement costs used were as follows, in shillings per hour:

One-way disk	1·49	Grain drill (306)	1·00
Tandem disk-harrow	1·00	Atkinson spreader	1·00
Drag harrow	0·16	Groundnut digger	1·87
Planter (433)	2·39	Ridging	1·87
Inter-row cultivator	1·87	Combine threshing (maize)	18·87
Lilliston weeder	0·16	Ransome thresher (groundnuts)	7·07

Fertilizer.—The cost on site of 1 cwt. ammonium phosphate in Dec. 1949–Jan. 1950 was 33*s.*

Manual Labour.—The hours of work for each operation were recorded. A man-day was taken at 8 hours, and the cost at £50 per year, which includes rations and an element of indirect costs. No account was taken of overheads. For example, time lost as a result of wet or otherwise unfavourable conditions has not been charged.

In a relatively small operating unit such as a farm of 1,500–3,000 acres, there should be little loss due to these causes as compared with a larger unit, since, for example, the fewer men there are, the greater the degree of supervision that can be applied. With a small force under direct supervision of a farmer, many hours lost in the field due to unfavourable weather conditions can be efficiently applied to other tasks owing to the greater flexibility of management that is possible. In a small force, too, the development of individual skill can be better fostered and unskilled labourers can be more rapidly developed into skilled farm-hands. The smaller force can also be effectively used round and about the farm, cleaning implements, filling up holes in roads, carrying out minor building repairs, and other necessary works.

Seed.—The value of seed and produce is taken at its price on the farm in Dec. 1949 or July 1950 as follows (long tons):

Groundnuts £43. 0*s.* 0*d.*, Maize £15. 12*s.* 6*d.*, Sorghum £13. 12*s.* 6*d.*

These values are based on the prices offered to the Corporation by the Ministry of Food which were well below the free market price at the relevant times.

Bags.—Bags were priced at 3*s.* each, and for groundnuts it was assumed that they would be used twice. Although for costing purposes a bag was taken (from large-scale records) as containing only 70 lb. of unshelled nuts, the average weight in the bag was actually 80 lb. Where great quantities of nuts are to be gathered, the saving in bags, handling and transport charges at the higher level of efficiency will be of considerable significance.

Times of Operation

Mechanical operations.—The areas and times of mechanical operations for the three crops separately and in total are shown in Table 4. The results for individual plots of each crop are added together to give a combined value for the crop.

Hand operations, groundnuts (*Table* 5).—The number of days required for weeding this crop does not appear to be unduly high. On the other hand, 200 man-days spent on gleaning 32 acres does seem high, but they yielded 2,840 lb. of kernels. At £50 per year the labour cost was 553*s.*, and at £43 a ton the yield was worth 1,090*s.*, so that the

TABLE 4. *Areas and Times of Operations in production of Groundnuts, Maize, and Sorghum, on Pilot-costings Plots. Urambo, 1949–50*

Operation	Groundnuts			Maize			Sorghum			Total			Hours per acre. General average for Urambo production areas
	Acres	Hours	Hours per acre	Acres	Hours	Hours per acre	Acres	Hours	Hours per acre	Acres	Hours	Hours per acre	
One-way disking [a]	32·2	32·0	1·00	25·7	25·7	1·00	23·7	23·7	1·00	81·7	81·5	1·00	1·30
Tandem disk-harrowing	5·9	4·0	0·68	14·0	5·5	0·39	23·7	13·0	0·55	43·6	22·5	0·51	0·52
Zig-zag harrowing	26·3	10·5	0·40	..	..	..	..	..	..	26·3	10·5	0·40	0·36
Planting	32·2	26·3	0·82	25·7	14·0	0·54	..	..	..	57·9	40·3	0·69	0·79
Drilling	..	..	..	..	..	..	23·7	4·6	0·19	23·7	4·6	0·19	0·37
Lilliston weeding	32·2	21·2	0·66	12·7	5·0	0·39	60·5	21·5	0·36	105·4	44·7	0·45	0·34
Cultivating and ridging	64·4	69·5	1·08	..	..	..	..	..	..	64·7	69·5	1·08	0·66
Digging	32·2	28·3	0·88	..	..	..	..	..	..	32·2	28·3	0·88	0·62
Fertilizer spreading	..	..	..	..	..	..	23·7	5·3	0·22	23·7	5·2	0·22	[b]
General—tractor	..	67·7	2·10	..	5·8	0·22	..	6·0	0·25	81·7	79·5	0·97	..
Combining	..	..	..	..	..	..	23·7	20·5	0·86	23·7	20·5	0·86	[b]
Combine threshing	..	..	..	..	23·5	0·91	..	..	..	..	23·5	0·91	..
General—combine	..	..	..	..	..	..	..	9·0	0·38	..	9·0	0·38	..
Ransome's thresher	32·2	74·0	2·30	..	..	..	..	..	..	32·2	74·0	2·30	..
Total [c]	32·2	333·5	10·36	25·7	79·5	3·10	23·7	103·6	4·37	81·7	516·6	6·32	..

[a] estimated time. [b] no production record. [c] total hours of work actually recorded on total acreage; hours/acre represents the average value, not the total of the column above it.

input was fully covered in this case. At the present level of efficiency of mechanization a significant proportion of the groundnut crop is usually left in the ground. An effort to secure this part of the crop is justified in most cases.

Stooking will prove to be no less a problem than gleaning; in fact, of the two it is likely to cause more trouble. Experience at Urambo has already shown that it is not enough to dig the nuts and leave them on top of the ground until rains cease. Germination of the harvested crop resulting in severe loss is inevitable unless the nuts are stooked or dried within a short time of being lifted. At present mechanization can neither stook nor glean the lands as economically or as expertly as hand-labour. Evidently much research is needed on this question.

The force needed for gleaning and stooking plus that required for the other hand operations shown will represent a most acute problem. A casual labour force of the magnitude indicated by the present results raises immediately a social problem, in that it is not desirable to maintain a large labour force for harvest work only.

Hand operations, general.—The hand-labour used for each crop is shown in Table 5.

TABLE 5. *Times of Hand Operations in Production of Groundnuts, Maize, and Sorghum on Pilot-costings Plots, Urambo, 1949–50*

	Hours	*Hours per acre*	*Man-days per acre*
I. Groundnuts (32·2 acres):			
Weeding	205	6·4	0·8
Windrowing	764	23·7	3·0
Stooking[a]	1,180	45·5	5·7
Gleaning	1,616	50·1	6·3
General duties—cultivations	150	4·7	0·6
harvesting	547	17·0	2·1
Total	4,462	139·0[b]	17·4[b]
II. Maize (25·7 acres):			
Weeding and roguing	303	11·8	1·5
Cutting and stooking	502	19·6	2·4
Picking cobs	305	11·8	1·5
General duties	219	8·5	1·1
Total	1,329	51·7	6·5
III. Sorghum (23·7 acres):			
Weeding and roguing	207	8·7	1·1
Hand gleaning	579	24·4	3·0
General duties	105	4·4	0·6
Total	891	37·5	4·7

[a] 26 acres only.

[b] Total acreage and total hours used in computing this value.

Hand operations, Maize and Sorghum. In a mechanized system of agriculture hand-labour figures of nearly 7 and nearly 5 man-days per

acre for maize and sorghum respectively seem high, but if these crops are grown in rotation with groundnuts these requirements do not cause a separate problem, since the labour peaks for the three crops do not coincide.

Weeding requirements for maize and sorghum (1·5 and 1·1 man-days per acre respectively) are higher than for groundnuts (0·8 man-days per acre) which can bear more intensive mechanization. Hand-gleaning (after combining) accounted for 3 of the man-days needed for sorghum, and tasks related to harvesting for 4 of those needed for maize. Neither of these tasks need occur at the time of groundnut harvesting.

It is to be noted that weeding and roguing costs are combined for sorghum and maize. The roguing was carried out because it was intended to use the produce for seed. Nevertheless, although the crop carried this extra charge, the return on the crop has been calculated not on the value of seed, but on the lower value of export produce.

Yields and Costs

Yields.—The yields for the three crops are shown in Table 6. The figures for groundnuts represent kernels, taken as 70 per cent. of the weight of pods. This value is slightly below the general value for shelling percentage at the Urambo Experimental Station in the 1949–50 season (72 per cent.).

TABLE 6. *Yields of Groundnuts, Maize, and Sorghum on Pilot-costings Plots, Urambo, 1949–50*

Crop	*Area acres*	*Main harvest lb.*	*Gleaned lb.*	*Total lb.*	*Yield per acre lb.*
Groundnuts (kernels) . . .	32·2	29,001	2,841	31,842	995
Maize	25·7	26,943	..	26,943	1,046
Sorghum (grain) . . .	23·7	18,580	8,245	26,825	1,129

The yield of groundnuts is within the range of normal yields for the season at the Urambo Experimental Station, but the yields of both cereal crops are low, compared with what might reasonably be expected on past experience at the station.

Direct costs and income.—From the figures given above for mechanical work, labour, and yields, the direct costs and income have been computed in accordance with the values given on pages 267 and 268. The costs of production and value of produce are given in Table 7.

Discussion

The data here presented give a considerable amount of detail concerning agricultural operations on a sample area of 82 acres, divided into plots of various sizes carrying the three crops. The objections to results obtained from very small plots do not apply here. The plots were, however, of a size such that precise recording was possible, which is not usually the case with the records of large-scale production.

TABLE 7. *Summary of Costs and Value of Produce of Groundnuts, Maize, and Sorghum on Pilot-costings Plots. Urambo, 1949–50*

	Crop		
	Groundnuts (32·2 acres)	*Maize (25·7 acres)*	*Sorghum (23·7 acres)*
DIRECT COSTS		(*s./acre*)	
1. Labour and Power:			
Cultivations and planting:			
Manual labour	3·85	4·47	3·81
Tractor and implement	43·92	16·83	24·31
Total	47·77	21·30	28·12
Harvesting:			
Manual labour	43·92	13·19	9·00
Tractor, combine, thresher	24·12	20·52	30·59
General, crop movements, &c.	14·77	1·58	1·79
Total	82·81	35·29	41·38
Total Labour and Power	130·58	56·59	69·50
2. Seed	19·00	1·25	2·19
3. Fertilizer	33·00	33·00	33·00
4. Bags and other direct costs	32·00	9·50	10·25
TOTAL DIRECT COSTS	214·58	100·34	114·94
VALUE OF PRODUCE, approx.	382·00	146·00	137·00
EXCESS OF INCOME OVER DIRECT COST, approx.	167·00	46·00	22·00

Hand-labour.—Hand-labour in this context refers strictly to unskilled labour. For groundnuts it represented 44·77*s.* per acre, or 22 per cent. of total costs; for maize 17·66*s.* or 18 per cent.; for sorghum 12·81*s.* or 11 per cent. The mean value is about 20 per cent., although this would naturally be affected by the proportions of different crops in the rotation.

Tractor costs.—The average tractor-hours worked per acre on agricultural operations over the 82 acres was 4. It remains to be seen whether this low value can be generally realized in large-scale practice.

Total costs.—The average total direct cost of production, 149*s.* per acre, compares favourably with previous estimates. If, however, a higher proportion of groundnuts than is included in the present sample were to be grown, the average costs will be higher than this value. If groundnuts only were to be grown, the costs, according to the present evidence, would total 215*s.* per acre. It appears that the cost of harvesting groundnuts (83*s.* per acre) is higher than has been expected hitherto. Seed in each case was the lowest item of cost, harvesting costs the largest. Fertilizer, which accounted for 15 per cent. of total direct costs for groundnuts, was 33 per cent. and 29 per cent. of total direct costs for maize and sorghum respectively, on account of the low level of other direct costs for these two crops.

Yields.—Table 7 shows the value of yields for all three crops. The value per acre for groundnuts at 382*s.* with total direct costs of 215*s.* leaves a margin of 167*s.* for overheads and return of capital. Maize and sorghum are not so satisfactory, and even although the direct costs are not quite half so high as those for groundnuts, the excess of income over expenditure would not be sufficient for economic success were these crops only to be grown. Where they are grown in such a way that operations on them do not coincide with the peak period of work on the groundnut crop, and as a part of a mixed-cropping economy, it might prove profitable to grow them even with these low margins. The levels of yield in these experiments are in all three cases considerably above what had been realized by the production units and farms of the Corporation before the 1950–1 season. This is in part due to the relatively small scale of the present sample, and the closer degree of supervision which is possible on an experimental farm, but it also reflects the greater experience of the staff concerned.

Conclusions

1. The groundnut crop can be most profitable, but will require more mechanization, more labour, and much higher costs generally than a cereal crop.
2. A high concentration of casual labour is inevitable at present technical levels of mechanization from cultivation time onwards; this is especially so for groundnuts, but further research on the mechanization of harvesting, and the use of longer-season varieties, should reduce this concentration.
3. Since it is not socially desirable to have labour dependent on casual employment it is necessary to study the possibility of developing a system of agriculture so balanced that it will keep a big proportion of the necessary workers employed throughout the year.
4. Although maize and sorghum are not so profitable as groundnuts it would probably be economical to grow them so far as they can be handled outside the peak periods of work on the groundnut crop.

Summary

In the 1949–50 crop season precise costings data, covering machinery and labour costs, were obtained for 32 acres of groundnuts, 26 acres of maize, and 24 acres of sorghum at the Urambo Experimental Station, Overseas Food Corporation. In the analysis of the data the times of operation or of hand-work actually recorded have been used. The costs of operation used in the computations are, however, not those recorded in the trials. Instead the somewhat higher operation costs of the Corporation's production units in 1950 have been used to make the results more representative. Implement operation costs are presented as well as tractor and combine costs. The costs presented are direct operational costs only.

The yields, direct costs of production, cash value to the Corporation on the farm in July 1950 (Ministry of Food price less transport, handling,

sea freight and insurance), and excess of income over direct costs, were as follows:

	Yield (lb. kernels or grain/acre)	*Direct cost of production (s./acre)*	*Cash value on the farm (s./acre)*	*Excess of income over direct costs (s./acre)*
Groundnuts . .	995	215	382	167
Maize . . .	1,046	100	146	46
Sorghum . . .	1,129	115	137	22

The groundnut yield was in the range of usual yields on the experimental farm during the season, but the yields of the cereals were regarded as low. At the same time all three yields were far above the levels obtained previously in large-scale practice. No allowance is made for overheads.

Groundnuts have provided a considerable margin of income over direct costs. Maize and sorghum are not so profitable, but it would probably be economical to grow them in addition to groundnuts so far as they can be handled outside the peak periods of work on the groundnut crop.

Hand-labour requirements in man-days for all three crops are high: this reflects in part the present inefficiency of mechanization of these crops under tropical conditions. Whilst the acreage analysed is sufficiently large to provide useful and reliable information, it would be impermissible at present to extrapolate the results to the acreages of large-scale production.

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STUDIES ON THE FERTILITY OF GOLD COAST SOILS

Pt. II. THE NITROGEN STATUS OF THE SOILS

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A GENERAL description of a programme of fertilizer trials in which sulphate of ammonia was one of the treatments has been given in Part I of this series (this *J.*, 1951, **19**, 217). In this paper the yield-responses to sulphate of ammonia given by the different crops are summarized and related to the carbon/nitrogen ratio of the top soils, and to the previous vegetation and cropping history of the sites. The effects of different times and rates of application of sulphate of ammonia are also summarized and discussed.

The Responses to Sulphate of Ammonia

The effects of a dressing of 2 cwt. per acre of sulphate of ammonia in all the trials (both 2^5NPKLM and 3^3NTP) are summarized in Table 1. The effects in each trial are averaged over all the other treatments.

It will be seen that the nitrogen responses of the test crops fall into groups, according to the climate and natural vegetation of the sites and their previous cropping. The previous cropping of the sites in savannah areas has in turn been correlated with the C/N ratio of the top soils. The time of planting and length of the growing-season of the crop has also a bearing on the response to nitrogen.

Forest and Southern Fringing Forest.—In this region there is little evidence of a shortage of nitrogen over the range of conditions covered. Some of the sites had been freshly cleared from forest, others were cleared from low bush after resting for 2 or 3 years, and the remainder had been cropped for 1 or 2 years previously. In only one instance had there been continuous cropping for more than 5 years, and the response was negative. Only one significant positive response was obtained, on maize at Mampong, and this represented an increase of less than 10 per cent. of the mean yield. Two significant negative responses on maize are attributable to depression of germination and early growth (see Pt. I).

The total organic-carbon content[2] of the top soils (0–6 in.) fell between 0·7 and 2·8 per cent. and the total nitrogen[3] between 0·066 and 0·229 per cent. There is no clear relation between the small nitrogen responses or the site histories and the C/N ratios, which fall between 10·8 and 14·6.

Savannah. Voltaian Soils. (*a*) *Long-resting-period sites.*—On the Voltaian soils of the Savannah, the sites recently cleared after a long period of rest under bush fallow are seriously short of available nitrogen, and high responses have been obtained on all test crops. In contrast, the sites in the more densely populated areas that are cropped more

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[2] Determined by the Walkley and Black method [1].

[3] Determined by the Kjeldahl method [2].

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TABLE 1. *The Effects of a Dressing of 2 cwt. per Acre of Sulphate of Ammonia*

	No. of trials with				Total no. of trials	Mean responses[1] to 2 cwt. per acre of S/A. %
	Positive effects		Negative effects			
	sig. at $P = 0.05$	not sig.	sig. at $P = 0.05$	not sig.		
1. *Forest and Southern Fringing Forest:* (*a*) *Undisturbed sites*[2]						
Maize (1)	0	7	0	2	9	3
Maize (2)	0	1	0	2	3	−5
Cassava	0	1	0	2	3	3
(*b*) *Disturbed sites*						
Maize (1)	1	3	2	1	7	1
Cassava	0	4	0	0	4	3
Groundnuts	0	1	0	2	3	−2
2. *Savannah. Voltaian soils:* (*a*) *Long-resting-period sites*						
Maize (1) and (2)	8	0	0	0	8	42
Guinea-corn	5	1	0	0	6	26
Rice	1	0	0	0	1	41
Sunflower (1) and (2)	3	0	0	1	4	19
Cassava	1	1	0	0	2	11
Yams	1	3	0	1	5	11
Groundnuts	4	7	0	2	13	9
(*b*) *Short-resting-period sites*						
Maize	4	4	0	2	10	17
Guinea-corn	4	3	0	0	7	24
Late millet	0	3	0	0	3	13
Yams	2	2	0	2	6	10
Groundnuts	0	2	3	2	7	−9
3. *Savannah. Northern Granite soils*						
Guinea-corn*	3	2	0	3	8	19
Late millet*	5	1	0	0	6	26
Early millet†	3	3	0	0	6	31
Groundnuts	0	2	1	3	6	−4
4. *Savannah. Greenstone soils*						
Guinea-corn	1	1	0	0	2	17
Late millet	1	0	0	0	1	38
All sites						
Maize (1) and (2)	13	15	2	7	37	14
Guinea-corn	13	7	0	3	23	22
Late millet	6	4	0	0	10	24
Early millet	3	3	0	0	6	31
Sunflower	3	0	0	1	4	19
Rice	0	1	0	0	1	41
Cassava	1	6	0	2	9	5
Yams	3	5	0	3	11	11
Groundnuts	4	12	4	9	29	1

* 3 sites mixed with early millet † all sites mixed

[1] All yields are of tubers, dry grain, dry seed, or dry shelled nuts.
[2] See Part I for an explanation of the grouping of the sites.
(1) = first season. (2) = second season.

frequently do not give such high responses. Every one of the eight maize trials at the four long-resting-period centres gave responses significant at the 1 per cent. point; and it is interesting that on some of the sites even groundnuts proved short of nitrogen, particularly those on which they were the first crop after clearing.

The total organic-carbon values for the top soils (0–6 in.) of the 2^5 trial sites fell between 0·39 and 0·91 per cent. and the total nitrogen between 0·026 and 0·067 per cent. This range is considerably lower than that for the forest trial sites; and the explanation is to be found in the higher soil temperature during the dry season, and the much lower annual production of vegetation. In general also, it has been found over all the soils that the coarser and more open the texture of the top soils the less is the organic matter they contain.

The C/N ratios of the top soils of the trial sites are interesting, because they are very high and reflect the undecomposed condition of much of the soil organic matter. At Ejura the values fell between 14·7 and 17·4; at Yendi between 13·3 and 14·0; at Kassei between 15·2 and 16·1; and at Damongo between 14·7 and 16·0.

There is a general impression from these results that the sites are more seriously short of nitrogen in the first year after clearing than in the second and third, though there is no doubt that the shortage persists into the third year. Trials to determine how long the deficiency persists, and the place of groundnuts in effecting an improvement in the condition, have been laid down.

The relative insensitivity of yams to the nitrogen shortage throws an interesting light on the native practice of always opening the land with this crop.

(*b*) *Short-resting-period sites.* On the Voltaian sites of the savannah more frequently cropped, at Tamale and Nyankpala, the differences from the previous group are particularly marked for the maize and groundnut crop. Nitrogen on the average depressed the yield of groundnuts and in three of the seven trials the depression was significant. The leaves of the groundnut plants, however, nearly always showed better growth on the nitrogen-treated plots.

It was interesting to note at Nyankpala in 1948 that maize on three sites failed to respond to nitrogen, whilst the guinea-corn on two adjacent sites gave highly significant responses. The maize matures early in August, and the guinea-corn late in November.

The total organic-carbon values of the top soils fell between 0·16 and 0·57 per cent. and the total nitrogen between 0·013 and 0·049 per cent. The C/N ratios of the top soils of sites at Tamale and Nyankpala were consistently lower than those of the previous group. At Tamale they fell between 11·5 and 13·0; at Nyankpala between 11·6 and 13·9.

Savannah. Granite soils of far north.—On these soils, where cropping has been almost continuous, responses have been similar to those on the frequently cropped Voltaian soils, the cereals showing marked responses and the groundnuts a negative response on the average. Early millet, which in the far north takes the place of early maturing maize, shows a high percentage response.

Total organic carbon and total nitrogen in the top 6 in. remained low, the carbon falling between 0·16 and 0·49 per cent. and the nitrogen between 0·016 and 0·056 per cent. These values are similar to those at Tamale and Nyankpala. The C/N ratio of the sites, however, fell between 8·2 and 11·9. This is a lower range than that in the frequently cropped Voltaian soils and reflects the continuous cropping, and possibly the more frequent use of legumes in the rotation.

Savannah. Greenstone soils of far north.—On the greenstone soils of the far north, data are scarce, but in the three trials at Zanlerigu the guinea-corn and late millet have shown responses similar to those on the granite.

When all the trials are considered together the order of percentage response is first the cereals, with rice and early millet the most responsive, then the root crops, and lastly groundnuts.

Experiments on the Rate and Time of Application of Nitrogen

The 1949 series of trials on the rate and time of application of sulphate of ammonia was carried out only in savannah, since nitrogen had not proved effective in forest in the 1948 series of trials. The rates of application were 0, 1, 2 cwt. per acre and the times of application were: early, at planting time; late, at the first sign of flowering; and split, half the dressing early, and the other half late.

The general picture of the fluctuation through the year of the available nitrogen (nitrate) in savannah areas with a single rainy season has been given by Hartley and Greenwood [3] as a result of studies at Samaru in Northern Nigeria where conditions are very similar to those on the far northern granite soils of the Gold Coast. They showed that there was a considerable production of nitrate early in the rains in April and May. With decreasing production and intense leaching the nitrate-content fell off steadily, and from August until the next rains it remained at a very low figure. This work was carried out on a soil frequently cropped. It seems likely that on sites freshly cleared after a long fallow the early increase in the soil nitrate is very much reduced.

The results given in Table 2 are divided between the long-resting-period sites and the short-resting-period sites.

TABLE 2. *Yields (lb. per acre) at Different Levels and Times of Application of Nitrogen*

Site	Rate of application			Sig. diff. $P = 0{\cdot}05$	Time of application			Sig. diff. $P = 0{\cdot}05$
	n_0	n_1	n_2		Early	Late	Split	
Savannah—Long-resting-period Sites								
Maize—First Crop								
Ejura 8 . .	2,030	2,461	2,534	218	2,321	2,678	2,491	267
Kassei 3 . .	1,888	2,251	2,449	171	2,457	2,312	2,278	209
Damongo 4 .	318	697	907	111	774	748	884	136
Mean . .	1,392	1,802	1,963	..	1,850	1,913	1,884	..
Maize—Second Crop								
Ejura 8 . .	1,043	1,230	1,486	241	1,343	1,345	1,394	295

TABLE 2—*continued*

Site	Rate of application			Sig. diff. $P = 0{\cdot}05$	Time of application			Sig. diff. $P = 0{\cdot}05$
	n_0	n_1	n_2		Early	Late	Split	
Guinea-corn								
Kassei 5	669	828	947	148	910	842	910	181
Damongo 5	363	437	522	102	570	459	408	125
Mean	516	632	734	..	739	650	659	..
Rice								
Ejura 11	794	1,100	1,213	356	1,343	944	1,182	435
Sunflower—First Crop								
Kassei 6	1,038	1,043	1,270	153	1,207	1,071	1,190	187
Sunflower—Second Crop								
Kassei	726	726	601	180	646	646	697	220
Cassava								
Ejura 10	12,327	15,621	12,582	5,395	13,490	14,535	14,255	6,599
Yams								
Ejura 7	9,053	9,071	10,367	1,423	10,085	9,485	9,631	1,774
Damongo 3	6,753	6,764	6,594	1,614	5,185	8,313	6,529	1,975
Mean	7,903	7,919	8,483	..	7,631	8,896	8,076	..
Early millet—Second Crop								
Kassei 3	482	578	771	163	978	391	655	199
Savannah—Short-resting-period Sites								
Maize								
Tamale 6	1,145	1,247	1,304	226	1,250	1,318	1,258	277
Nyankpala 12	403	454	505	52	476	485	476	64
Yendi 7	845	1,208	1,372	127	1,420	1,131	1,318	156
Mean	798	969	1,059	..	1,048	978	1,017	..
Guinea-corn								
Tamale 7	459	567	578	142	544	561	612	170
Nyankpala 13	1,128	1,162	1,242	460	1,165	1,241	1,199	563
Yendi 6	902	924	936	74	901	893	995	94
Zuarungu 3	760	879	953	183	944	850	952	224
Manga 3	839	975	1,355	233	1,088	1,139	1,267	289
Tono 5	714	731	845	211	740	859	765	258
Mean	800	872	984	..	896	923	964	..
Late millet								
Tamale 8	278	334	289	88	315	315	306	107
Nyankpala 14	357	374	420	111	374	425	391	136
Yendi 8	646	697	748	147	688	748	731	187
Zuarungu 4	493	595	669	96	570	672	655	117
Manga 4	397	567	590	86	493	604	638	105
Tono 3	680	856	913	171	825	884	944	209
Mean	475	570	604	..	544	608	611	..
Yams								
Tamale 5	2,778	2,925	2,704	1,406	2,533	3,221	2,686	1,720
Nyankpala 11	9,537	10,643	11,555	1,978	11,535	11,016	10,727	2,419
Yendi 5	1,196	1,349	964	683	1,326	1,275	867	835
Mean	4,504	4,970	5,072	..	5,131	5,171	4,760	..

Long-resting-period sites. Time of application.—On these sites cereals show increased growth in their first month on the nitrogen-treated plots. However, in the final yield it made little difference to maize, which has a growing-period of about 110 days whether the nitrogen was applied at planting time or at flowering time, about 55 days after planting. At Ejura the late application was significantly better than the early, but at Kassei and Damongo the early applications were better, though not significantly so. The preference for the early application was more marked with the other cereals, especially upland rice, which has a growing-period of about 150 days, the late nitrogen being applied after 85 days. Applications at both times greatly increased tillering, but the late tillers set no seed.

There was a trial on yams, at Ejura and at Damongo. Unfortunately at Damongo, where the nitrogen was broadcast before the land was ridged up for yams, the early application caused a depression of yield, and consequently the late application (applied 4 months later in August) that was applied on top of the mound was very significantly better. At Ejura, on the other hand, where both early and late applications were broadcast over the mound, the early application was better though not significantly so.

A trial on first-crop sunflower at Kassei showed the early application to be better than the late (nearly significant) applied 35 days after planting. The sunflower crop had a growing-period of 100 days. Second-crop sunflower did not respond to nitrogen.

No conclusions can be drawn from a trial on cassava at Ejura because of a very high error due to rotting of the tubers.

In general the evidence is that on these sites very short of available nitrogen, the fertilizer should be applied about planting time to all crops (except December-planted yams when the fertilizer should be spread about April). Results for the split application were nearly always intermediate between the early and late, and there does not appear any advantage in this method of application.

Long-resting-period sites. Rate of application.—On maize and rice the response to the single dressing of 1 cwt. per acre of sulphate of ammonia was in every case well over half the response to the double dressing of 2 cwt. per acre. On both guinea-corn trials the response to the single dressing was about half that of the double dressing. On yams at Ejura and first-season sunflower at Kassei, the single application gave a very small increase in yield compared with the double, results that can probably be ascribed to random error.

Sites frequently or continuously cropped.—The results for the Voltaian and Northern Granite and Greenstone soils are grouped together in Table 2.

There is a marked difference in behaviour between the early-maturing maize and the late-maturing guinea-corn and late millet. At both levels of fertilizer, maize on the average yielded better to the early than the late dressing. The response to the single dressing was again well over half that of the double. There were unfortunately no trials on early millet in the far north, where it takes the place of maize, but a trial on

this crop at Kassei, where it may be grown as a second-season crop, showed a high response to the early application but no response to the late.

On both guinea-corn and late millet, planted at the end of May, the fertilizer was observed in nearly all these trials to depress germination and early growth, especially if the planting-season was dry. The plants began to show signs of shortage of nitrogen in August, the third month of growth, and in this month the nitrogen-treated plots usually caught up. The late applications were applied in mid-September, and the crops were harvested between the end of November and the end of December. The beneficial effects of the late application on the leaves were striking. In the final yield of both guinea-corn and late millet, each averaged over six trials, the split dressing is better than the late dressing which in turn is better than the early dressing. There is, however, a marked difference in the effect for the two levels. At the early application the single dressing gives a very poor increase, 5 lb. for guinea-corn and 41 lb. for late millet, whilst the double application gives an increase of 189 and 97 lb. respectively. It seems that the heavy August and September rains wash away most of the single application, but at the double rate there is some left for the plant. On the other hand, when the application is made late, towards the end of the heavy rains, the single dressing is sufficient for the plant, and the response to the double dressing is no greater on either crop. The yield from the single split application is rather less than that from the late, but the yield from the double split application is much better than that of the single late. As the double split application is equivalent to a single application early and a single application late this supports the field observation that the plants can make use of nitrogen about 6 weeks before the late application was made.

The conclusion may be drawn that the nitrogen may best be applied to guinea-corn and late millet in August, when the initial concentration of soil nitrate has fallen and the plants are well established; and, possibly, a portion reserved until after the heavy September rains.

When maize or early millet is grown in mixed stand with guinea-corn or late millet it will probably be necessary to place part of the nitrogen on the early-maturing crop soon after planting and reserve part for the late-maturing crop to be applied later.

In the three yam trials there was a significant response to nitrogen only at Nyankpala, and there the early application was slightly better than the late. In the other two trials the yields were too poor to allow any general conclusions to be made.

Summary. No appreciable responses to sulphate of ammonia have been obtained in forest. In savannah, land which has been left to rest for periods of 10 years or more is very short of available nitrogen for the first 3 years of cropping and large responses have been obtained on all crops. These sites have very high C/N ratio values. On land more frequently cropped, cereals and yams have given moderate responses and groundnuts negative responses. Sulphate of ammonia is best applied about planting time to all crops, except guinea-corn and late

millet in frequently cropped areas, on which applications in August are recommended. One cwt. per acre of sulphate of ammonia is probably the most profitable rate of application.

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BANANAS IN EAST AFRICA

Pt. I. THE BOTANICAL AND AGRICULTURAL STATUS OF THE CROP

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Introduction.—The notes on which this paper is based were made in September–November 1948 in Kenya, Uganda, Tanganyika, and Zanzibar. The aims of the tour, which was planned and carried out under the Banana Research Scheme, were to see if there were any varieties of banana in East Africa likely to be of practical or scientific value for the Scheme; and to investigate the general botany of the wild bananas of the area. The tour started at Nairobi and went round Mount Kenya and to Kisumu; thence to Entebbe, Fort Portal, and Bukoba; a short visit was paid to the Groundnut Scheme headquarters at Kongwa *en route* for Dar-es-Salaam, Zanzibar, Amani, Moshi, and Nairobi, where the tour ended.

Collections of edible bananas are being sent to the Imperial College of Tropical Agriculture by way of quarantine at the Royal Botanic Gardens, Kew. Specimens and photographs of, and notes on the wild bananas have been deposited in the Kew Herbarium but have not yet been worked out; details will ultimately be published elsewhere so that this paper is solely concerned with the cultivated varieties. The general account of the botanical and agricultural status of the crop here given will be followed (in Part II) by an annotated list of all varieties recorded. This list has been checked for spellings, meanings of native names, and local usage of varieties by various gentlemen and organizations to whom our indebtedness is recorded below. It is, however, too much to hope that no errors have been made and for these we alone must be held responsible.

We express our thanks and deep indebtedness to the directors and staffs of the Agriculture and Forestry Departments of the various territories; of the East African Agricultural and Forestry Research Organization; of the Overseas Food Corporation; and of the Royal Botanic Gardens, Kew, for much kindly help and interest throughout the tour and afterwards.

General Notes on Localities

Notes on the status of the bananas cultivated in eight localities are given below. The main points concern locality, importance, usage, and varieties.

KENYA. *Kiambu.* Bananas were studied in native *shambas* in the Kiambu reserve and, to a less extent, at Karaguine near Fort Hall, and in the Nyeri region. The crop is important though not staple, having largely

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been replaced by maize. The Wakikuyu distinguish between 'man's' and 'woman's' varieties but are not very particular as to usage. Fruits are either eaten raw or boiled or roasted; the making of banana beer was not recorded. Varieties: the native-alien distinction is sharp; sixteeen and six varieties or varietal names respectively were recorded.

North Nyanza District. Crops were studied in native *shambas* at Luanda and Maragoli and at Masena Farm, but they were quite unimportant locally. Fruits are eaten raw or boiled; the making of banana beer was not recorded. Usage is not strict, one variety commonly being eaten raw or boiled according to taste. The native-alien distinction between varieties is sharp; eleven and four varieties or varietal names respectively were recorded.

UGANDA. *Kawanda and Bukalasa.* Varieties were examined in the collections of the Department of Agriculture at the two stations named. That at Kawanda is the more complete but it lacks a few forms represented at Bukalasa. Between them, these collections probably contain virtually all the varieties in Buganda. The banana crop of Buganda was staple and highly cultivated, though its importance and the level of cultivation have declined in recent years as a consequence of the increasing use of maize and sweet potatoes [1]. In particular the old system of trashing and mulching was of an excellence equalled only at Bukoba. Usage is apparently rather strictly defined, one variety being used for one purpose only. (Thomas in [1] would, however, hardly agree with this statement.) There has been a recent trend towards using sweet bananas and *gonja* varieties for beer (e.g. Kisubi) and, in general, some relaxation of custom seems to be occurring. The general Luganda name for the plant is *bitoke* and four groups of varieties are distinguished according to usage. *Nkago* refers to the fruits of varieties that are boiled or steamed to make the porridge, *matoke*; *gonja* refers both to the raw and to the roasted fruit of the appropriate varieties. The fruits of beer varieties are called *mbidde*; they are made into a sweet drink (*mubisi*) or are peeled, mashed, fermented in a wooden dug-out, and strained to give beer proper (*mwenge*) [2]. *Menvu* refers to the fruit and food derived from bananas that are eaten raw. The native-alien distinction between varieties is sharp, the aliens rarely grown in native gardens. Sixty-one native varieties or varietal names were recorded and six aliens.

Toro and Ankole. Bananas were studied in native *shambas* around Fort Portal and Kyamahunga, localities where the crop is important though not staple. Much beer is made which is commonly traded for fish with the folk living on the lakes (e.g. by the Kazinga Channel on the NE. of Lake Edward). Usage is much the same as in Buganda. Beer is commonly made from a mixture of bananas and sorghum flour (*Muwemba*—Luganda; *Mugusa*—Lutoro, Ankole). The native-alien distinction is sharp. Twenty native varieties or varietal names were recorded, often recognizably the same as Buganda varieties but bearing, of course, different names; there was one alien only.

TANGANYIKA. *Bukoba.* Bananas were seen in native *shambas* around the town; the crop is important and extremely well cultivated. The soils are poor, leached sands, but bananas are kept in permanent cultivation in

pockets of soil among the boulders by generous mulching with trash and household refuse. Bambarra groundnuts, sweet potato, millet, &c., increase where the climate is too dry or conditions otherwise unsuitable to bananas; but bananas are grown wherever possible. Usage is fairly strict, as in Uganda. Most fruit is boiled (i.e. steamed); roasting and beer-making are less important. The following words in the local language (Kihaya) were noted:

Ngemu, boiling variety; *Kitoke* (pl. *Vitoke*), food prepared from *Ngemu*; *Mbire* (or *Mkundi*), beer variety; *Muramba*, liquor before fermentation; *Marwa*, beer; *Moshi*, distilled liquor; *Nkonjwa*, roasting variety; *Mbabi*, trash; *Bishansha*, mulch; *Magogo*, fresh inside sheaths used for cleaning the hands before eating, special plants being kept for this purpose; *Byiai*, fibre from sheaths.

Seventeen native and three alien varieties or varietal names were recorded, the distinction between native and alien being sharply maintained.

Moshi. Bananas were studied in native gardens near Moshi on the southern side of Kilimanjaro and at the Coffee Experiment Station at Lyamungu, where Dr. G. B. Wallace maintained a small collection. The crop is an important one though hardly staple. It is, in general, well cultivated, the irrigated gardens of the Wachagga on the slopes of the mountain being particularly good. These people use much banana material for feeding stock [3] and, indeed, it was often hard to obtain male buds of a variety for botanical purposes. Lower down, towards Moshi, the country is drier but even there bananas are important, the hardy Mkojosi being the predominant variety as in similar situations in Zanzibar. Usage is rather flexible, all but a few varieties being boiled or eaten raw or made into beer indifferently. The Wachagga use virtually any part of the plant as food for stock. Twenty-five native varieties or varietal names and ten alien were recorded, the distinction being quite sharply maintained.

Amani. Varieties were studied around the East African Agricultural Research Institute [E.A.A.R.I.] and in the lower land eastwards towards Tanga; they were found to be rather different in the two regions and accordingly have been indicated in the list (in Part II) as characteristic of 'hills' or 'plains'. The crop is quite unimportant locally and, except around house-sites, is poorly cultivated. Usage is flexible, any one variety commonly being used in several ways, eaten raw, boiled, roasted, or dried and pounded to flour, but not, apparently, made into beer. The banana flour is frequently seen in native markets in the Usambaras and is eaten as a porridge; Mboko and Lualua are the most popular varieties for the purpose (P. J. Greenway, personal communication). Eighteen native and nine alien varieties or varietal names were recorded, the distinction being sharply maintained. Some of the aliens were introduced by the Germans [4] and others, more recently, by the E.A.A.R.I.

ZANZIBAR. *Kizimbani.* Varieties were studied in the excellent collection of the Department of Agriculture at Kizimbani. A visit was also made to Hanyegwa mchana on the dry coral land of the east coast. The

crop is relatively unimportant and poorly cultivated. Usage is flexible though beer-making is not practised. The native-alien distinction between varieties virtually does not exist; 40 varietal names were recorded.

History and Botanical Status of the Crop

The genus *Musa* is not native to East Africa and all the edible bananas grown there must have been imported as suckers; they cannot have evolved from wild bananas *in situ*. (The wild bananas of East Africa are now referred to as the genus *Ensete*, which is distinct from *Musa* in many characters and has not given rise to any edible forms.) The East African cultivars must have come originally from South-East Asia, from places in the vast region bounded by Ceylon, India, Burma, the Malayan Archipelago, and even down to New Guinea and the Philippines. The earliest writings about the coast of East Africa show that bananas were well established there in the Middle Ages [5] and it may be surmised that they had been present for centuries before that. Arab travellers employed upon the seasonal run between India and the African coast have commonly been supposed responsible for many if not all the older introductions, and this seems plausible enough. An alternative route by way of Egypt seems very much less likely [5].

It is not known to what extent the inland tribes of East Africa grew the banana in those early times and indeed it probably never will be known as a matter of historical certainty. The early travellers in the hinterland in the nineteenth century found the banana established as a staple crop in virtually every area suitable to it, and it may reasonably be surmised that it had been there a very long time to become so well established in the life and customs of presumably conservative native peoples. The means and routes by which the crop penetrated far inland are unknown. Probably the process would be one of gradual diffusion rather than of long journeys: at least this seems easier to imagine in a primitive country occupied by tribes each jealous of its own land and fearful and suspicious of neighbours and strangers. If this be admitted, the great semi-arid stretches behind much of the coast must be excluded as routes by which the crop might have moved. (It does not seem likely that climatic changes sufficiently profound to impugn this conclusion could have occurred in the last thousand years or so.) Two main routes into the hinterland are therefore suggested: one by Lakes Nyasa and Tanganyika to Lake Victoria and Uganda, the other by the Usambara mountains to Kilimanjaro. Both present tracts of land in which localities moist enough for banana cultivation are either continuous or nearly so.

These processes of introduction and spread may well have gone on down to the present time. For example, Kisubi is said to be a recent introduction to Buganda though now accepted there and commonly grown. In general, however, the banana-growing peoples are conservative in their choice and use of varieties and quite clear as to which varieties they regard as native and which as alien. Thus the Red banana of the West Indies appeared in every locality studied but never as an accepted native variety; its names associated it with Europeans or—

outside Uganda—with Uganda as a place of origin; in Uganda it had not even a local name.

Bananas are vegetatively parthenocarpic and effectively seed sterile; they must be propagated by suckers. Therefore genetical variation cannot be released by the ordinary processes of sexual reproduction, and divergence from the varietal type is limited to the effects of somatic mutation or bud-sporting. That these effects can in the long run be considerable is indicated by the fact that six mutants of the Gros Michel banana have been detected in Jamaica; they must have originated in about 100 years [6], and doubtless more have gone undetected. Several cases of similar varieties probably or certainly mutationally related were noted by the writers while in East Africa, and many more may plausibly be inferred. Thus at Kawanda, Nakabululu omudugavu seemed to be merely a black-stemmed mutant of Nakabululu; a sectorial chimaera of Red and Green Red was seen at Kiambu; and at Kawanda and Bukoba there exist complexes of cooking varieties so similar phenotypically that, if members are really distinct, somatic mutation seems a much more likely basis than true varietal difference in the sense of having independent origins. It is concluded that the accumulation of bud-sports may have added materially to the diversity of phenotypes and, in this sense, East Africa is a secondary centre of diversity of the crop; the degree of diversity possible is limited to what can be produced somatically, recombination by sexual reproduction being excluded.

Estimates of the numbers of varieties present in one locality are very hard to make and reliable figures could only be obtained by collecting them all together at one spot and conducting exhaustive field comparisons. Numbers of names are a bad guide, for they frequently reflect only the enthusiasm with which native growers distinguish small—often, one suspects, non-genetic—differences. Estimates of numbers of varieties exclusive to one area or common to two or more are still harder to make, for one sees the various plants at different times and under different circumstances with only general experience and field notes for a guide. Very broadly then (and subject to confirmation or rebuttal by the results of field comparisons), it is thought that there are about 50 varieties in the inland areas (Kenya, Uganda, Bukoba); about 30 varieties in the coastal areas (Moshi, Amani, and Zanzibar); and about 70 different varieties in all. These figures must include a considerable number of somatic mutants (perhaps more in the inland populations than in those of the coast), so that the numbers of original introductions must be considerably fewer, perhaps about a half or even less than half of the figures given above. It will be noted that the varietal populations of the inland and coastal areas are thought to be broadly different; if this is correct it should prove significant in a study of the history and migrations of the crop in East Africa. Is it to be attributed, for example, to a difference in the varieties reaching the coast at different places or at different times, one lot of introductions populating the coastal areas and hills inland to Kilimanjaro directly and the other travelling to the far hinterland by way of the great lakes? Or does it merely reflect ecological selection among a more or less homogeneous population of varieties?

No comment has yet been made upon the botanical origins of the crop and a few words may be useful here. The East African bananas are similar to cultivated bananas in the rest of the tropics in having the phenotypes of two wild Asian species of *Musa*, *M. acuminata* and *M. Balbisiana*, or of hybrids between the two [7, 8]. The great majority of the East African varieties are of *acuminata* origin; a few (such as the Koroboi of Zanzibar or Mkojosi of Moshi) approximate phenotypically to *M. Balbisiana*; and a few are of hybrid origin (e.g. the cosmopolitan Silk fig of the West Indies which appeared in Zanzibar, Amani, and Moshi as Kipukusa or Kibungala; and the Mysore banana in Zanzibar as Kikonde).

Agricultural Status of the Crop

The banana in East Africa is purely a local food crop and neither the geography of the region nor the varieties present are suitable to sustain an export industry. Thus the great distances of the inland growing-areas from shipping points on the coast, and the length of the haul by sea to markets in Europe, would prohibit the carriage of commercial varieties; and of the two commercial 'varieties' known that are adapted to naked bulk storage, Gros Michel is very rare in Uganda and the Congo-Lacatan complex was recorded only in Zanzibar.

Nevertheless, the importance of the banana as a food crop is, or was, very great. Indeed it seems to have been staple wherever rainfall and soils permit, and in the last analysis it is apparently only rainfall that matters, for at Bukoba excellent bananas are, by assiduous application of household refuse, grown on poor, leached sand among boulders. This is remarkable for it implies the utter dependence of many native peoples, spread over a great area, on an alien crop that can be propagated and disseminated only by bulky and delicate planting material.

Nowadays the level of cultivation is roughly proportional to the importance of the crop and, as alternative food-crops increase, so the cultivation of the banana declines. Thus at Bukoba, the crop is staple and magnificently cultivated. In Kenya maize, and in Uganda sweet potatoes, are replacing the banana and, concurrently, cultivation declines; the Baganda, for example, no longer maintain the level of mulching that they used to maintain. In Zanzibar, at the other extreme, the banana is quite unimportant and there it is a poorly cultivated backyard- rather than a field-crop.

The uses of the crop are numerous and they vary between peoples. Fruits are generally eaten boiled or steamed though some are roasted; much beer is made in some localities; and a few fruits are eaten raw. Raymond and Jojo [9] comment upon nutritive value. Broadly, the diversity and importance attached locally to mode of usage must have been high where the crop was staple, and this is reflected in the complexity of associated names and customs, as in Uganda and at Bukoba. Now, however, usage is becoming more and more uncritical and varieties are used unspecifically as the crop declines in importance.

Identity of Certain Varieties

Certain of the East African bananas are widely distributed through the tropics under various names and a few probable identities may be indicated here:

Dwarf Cavendish, *Chinese*, *Canary*, *Governor*, &c.: Nyoro at Kiambu, Malindi at Amani, Kimalindi or Kinguruwe at Moshi, Kiguruwe in Zanzibar, and present, though unnamed, elsewhere.

Guindy (of the I.C.T.A. but perhaps not of Madras), *Ney Poovan* (Madras), *Lady's finger* (British Guiana), &c.: 'Guindi' at Kiambu, Sukari in North Nyanza and Uganda, Kipukusa cha Java at Amani, Kisukari at Moshi, and present, but unnamed, elsewhere.

Silk fig (of the West Indies), *Rastali* (Madras), *Safet elchi* (Bombay), &c.: Kibungala at Amani, Kipungusa at Moshi, Kipukusa in Zanzibar.

Red, *Red Mataburro* (Trinidad), *Rajah Udang* (Malaya), &c.: Neuse at Kiambu, Nyekundu ya Kizungu at Amani, Kikanda, &c., at Moshi, Mzungu mwekundu in Zanzibar, and present, but unnamed, elsewhere.

Green Red, *Green mataburro* (Trinidad), *Talan* (Malaya), &c.: Nyeupe ya Kizungu at Amani, Ndizi Uganda nyeupe at Moshi, Mzungu mweupe in Zanzibar, and present, though unnamed, at Kiambu where a chimerical mutant bunch, half Red and half Green Red, was seen.

Sucrier (West Indies): Kisukari at Amani, China in Zanzibar.

Bluggoe, *Moko*, *Bokbok* (West Indies): Mkojosi at Moshi, Koroboi and Bokoboko in Zanzibar, Bokoboko at Amani, Kijozi and Kivuvu in Uganda.

Horn, *Horse Plantain* (West Indies): Mkono wa tembo at Moshi, Amani, and Zanzibar, Nkonjwa chayaya at Bukoba, and probably Gonja mamba in the Fort Portal region. A closely related form with slightly more numerous hands and fruits is Msusu (Mbwe or Mbo) at Moshi and Msinyore in Zanzibar.

French Plantain (West Indies): Muhoye at Amani and Kichaange in Zanzibar.

There are several other members of this plantain complex which cannot at present be identified with known varieties. They are: Mchinja damu, Mzuzu and Mporo moka in Zanzibar, Kipanje at Amani, and Nkonjwa at Bukoba.

Pests and diseases.—The banana weevil (*Cosmopolites sordidus*) is the only important insect pest. It appears to be a fairly recent introduction into the area and to be still spreading. It is present in Uganda and Eastern Tanganyika and, since there is no natural barrier between Uganda and the North Nyanza province of Kenya, it is probably only a matter of time before Kenya, too, is invaded. The weevil is serious in some varieties but others show a high degree of resistance. Trinidad experience is that it can be kept down in most varieties by thorough chopping and scattering of all trash, though this is ineffective in the case of a few highly susceptible forms, in particular the plantains.

Panama disease (*Fusarium oxysporum cubense*) is unknown in East Africa, though it should be noted that highly susceptible varieties by which its presence might be recognized are probably rare. It is present

in the Cameroons. Leaf spot (*Cercospora musae*) is common everywhere but not serious as a result, apparently, of the high degree of resistance shown by most native varieties. The alien Dwarf Cavendish or Chinese is very susceptible. Minor leaf-diseases, such as *Chloridium musae*, are common in the wetter districts. Cigar-end rot (*Stachylidium theobromae*) was noticed occasionally, particularly on the dwarf Cavendish or Chinese banana and on the Kikuyu variety Muraru. *Armillaria mellea* was seen once in Uganda.

Summary

Bananas in East Africa were a staple and highly cultivated crop wherever soils and climate permitted, but both importance and level of cultivation are now, in general, declining. They are native to South-East Asia and must have been introduced to Africa as suckers (not seeds) many hundreds of years ago. It is estimated that there are, very roughly, 70 varieties present, but this number probably includes an unknown number of somatic mutants. An annotated list of varieties will be given in Part II.

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GENETIC GAIN IN DAIRY CATTLE THROUGH SELECTION OF DAMS OF BULLS

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In the breeding of dairy cattle in Britain the yield of milk is presumably one of the main aims of herd-owners, and it may be supposed that they have practised some selection for it up to the present day. Milk yield is certainly one of the most important economic characters in dairy cattle and it would be desirable, therefore, to determine what effect selection has probably had on the average milk yields of different herds during a given time. A method of estimating the rate of genetic improvement for any known selection programme was suggested by Dickerson and Hazel [1], and its application to milk-yield data has been developed extensively by Rendel and Robertson [2]. This method has also been used by Mahadevan [3] for estimating the genetic gain through selection of dams of cows in some commercial herds. In the present paper the same method has been employed to determine the amount of selection that has been actually practised in the breeding of bulls.

Material and methods.—The material for this investigation covered the 10-year period, 1930–9, and was obtained from twelve leading herds of pedigree Ayrshire cattle situated in south-west Scotland.

The mean phenotypic superiority of the dams of bulls bred in each herd during this period was first determined by comparing the average age-corrected milk yields of each of the dams with the contemporary herd average. This phenotypic superiority was then converted to a genetic measure by multiplying it by the appropriate heritability (which was taken as 0·25 for single lactations). Owing, however, to the great variation in the number of daughters sired by the different bulls, it was necessary to weight each dam according to the number of daughters left by her son. The latter was obtained from a study of all the entries in the Ayrshire Herd-books for the years 1930 to 1947.

The above method of estimating genetic gain through selection of dams of bulls may be criticized on the ground that the observed scale of measurement (gallons of milk) may not be the ideal one to use for studies in selection. It is well known that the distribution of milk yields is skew with a long tail towards the high yields, and that such departures from normality are often due to the non-additive effects of factors. The distribution can, however, be considerably normalized by transforming the scale. A logarithmic transformation, for example, tends to normalize the frequency distribution very considerably. This transformation was therefore used for the present data in order to determine whether the estimates of genetic gain obtained on the original scale are very different from those on a more normal scale. It is extremely important to gather adequate information on this point, particularly in regard to the selection of dams of bulls, which are generally chosen from the top 5 per cent. of the herd.

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Results.—The selection of dams of bulls was studied separately for those bulls that were sold or transferred to other pedigree herds, and for those that were retained in the herd in which they were bred. It will be observed (Table 1) that the genetic superiority was about 5 gals. greater for dams of bulls that were retained in the herds as compared with bulls that were sold or transferred.

TABLE 1. *Selection of Dams of Bulls* (A) *Sold or Transferred and* (B) *Retained in the Herds*

(*'Raw' milk yields*)

A. BULLS SOLD OR TRANSFERRED

Herd	*Estimated genetic superiority of dams (based on the av. of 4 lactations) (gals.)*	*No. of bulls*	*No. of daughters*
A	40·9	9	230
B	85·5	3	79
C	−3·9	19	338
D	90·6	25	538
E	51·1	6	38
F	50·2	24	478
G	44·0	1	13
H	9·4	28	806
I	87·7	4	103
J	5·6	48	1,888
K	−6·8	1	36
L	46·0	64	4,099
Totals	35·3	232	8,646

B. BULLS RETAINED IN THE HERDS

A	22·3	9	51
B	63·0	5	59
C	27·5	14	107
D	96·3	15	52
E	39·7	8	38
F	46·8	7	109
G	80·1	7	26
H	21·9	22	109
I	63·3	4	28
J	61·0	9	43
K	73·4	3	63
L	21·8	19	300
Totals	40·0	122	985

The conversion of milk yields into logarithms yielded results that were only slightly different from those on the original scale (see Table 2). The procedure was to calculate the logarithms of the individual lactation yields of the dams and to compare the mean log for each dam with the herd mean log. The herd mean log itself was derived as follows: If m

is the mean on the original scale, m_T the mean on the transformed scale and c the coefficient of variation, then

$$m_T = \log m - \tfrac{1}{2} \log_e(1+c^2).$$

There is a fair amount of evidence to show that c is of the order 0·2 for milk yields, and this value has been used here.

Comparison of Table 1 A with Table 2 A and Table 1 B with Table 2 B shows that the log transformation has caused a reduction of only 1 to 5 per cent. in the estimate of the genetic superiority of dams obtained on the original scale.

TABLE 2. *Selection of Dams of Bulls*

(A) *Sold or Transferred*, (B) *Retained in the Herds*

The milk yields transformed to a log scale

Numbers of bulls and daughters are the same as in Table 1

A		B	
Herd	*Estimated genetic superiority of dams (based on the av. of 4 lactations) (gals.)*	*Herd*	*Estimated genetic superiority of dams (based on the av. of 4 lactations) (gals.)*
A	37·8	A	23·4
B	80·6	B	61·3
C	−0·2	C	28·3
D	76·5	D	88·1
E	40·9	E	39·3
F	49·5	F	47·5
G	49·7	G	73·7
H	9·6	H	24·1
I	89·1	I	65·9
J	6·0	J	56·3
K	−2·6	K	74·4
L	43·8	L	21·0
Total	33·5	Total	39·5

Discussion.—These estimates of the genetic superiority of dams of bulls in Ayrshire herds show fair agreement with the results reported by Rendel and Robertson for Kerry [2]. Their theoretical estimates show that under optimum conditions of selection the genetic superiority of the dams of herd sires would be of the order 0·103 $\bar{y}$ where $\bar{y}$ is the average yield of the herd. For the present data, $\bar{y}$ is in the region of 1,000 gals. This yields a possible superiority of 103 gals. as compared with the actual value of 35–40 gals. There are many reasons why these two values differ considerably, the most important of which is, perhaps, that all the selection in these herds was not directed towards milk yield only. Selection for other characteristics such as type and conformation would have tended to lower the selection differential on yield.

The slightly lower genetic superiority of dams of bulls that were sold or transferred to other herds as compared with those that were retained

for use at home was to be expected, because in normal herd practice the bulls out of the highest-producing cows would naturally be retained by the farmer to be used in his own herd. Whilst this is true on the average for the present data, considerable differences were found to exist between herds.

The results obtained after conversion of the milk yields into logarithms showed the same general trend as those observed on the original scale. The average genetic superiority was only 1–5 per cent. lower on the transformed scale than on the original scale. It may therefore be concluded that the 'raw' milk yields of dairy cattle provide sufficiently accurate estimates of genetic gain through selection.

Summary.—1. The average genetic superiority in yield of dams of bulls over other cows in the same herd in 12 leading herds of Ayrshire cattle in south-west Scotland was found to be 35·3 gals. for bulls sold or transferred to other herds, and 40·0 gals. for those retained in the herd in which they were bred.

2. Conversion of the milk yields into logarithms yielded estimates of genetic superiority which were only 1–5 per cent. lower than those on the original scale. It is concluded that estimates of genetic gain from selection are sufficiently accurate when they are calculated from 'raw' milk yields.

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THE EXTENT OF SELECTION FOR MILK YIELD IN DAIRY CATTLE

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IN his address to the 1948 Genetics Congress, Lush [1] discussed the relevance of heritability estimates to the genetic improvement shown in farm animals and suggested that there is at present some contradiction between the known values for heritability and the genetic changes found. 'This is a challenge and demands a solution. I have no solution in which I have strong faith, but the following possibilities are mentioned as worth examining. Perhaps the breeders have not been and are not yet practising as intense a selection as we think. Only a few fragmentary studies have been published. For the most part, they indicate that for some reason or other the actual average selection differential is smaller than most of us think.'

Rendel and Robertson [2] have made a theoretical investigation of the genetic improvement in milk yield that can be obtained by selection within a closed herd without progeny testing. The annual rate of improvement is governed by the intensity of selection (dependent on rates of replacement and reproduction), by the heritability of milk yield, and by the average generation-interval. With the most intense selection and the shortest generation-length possible, they showed that the probable genetic improvement is about 1·0 per cent. a year. Taking into account the actual generation-length, which is rather longer than that in the theoretical population, they suggested that the improvement in dairy herds is probably less than 0·6 per cent. a year. In actual cases, it is not possible to measure the genetic improvement directly because the steady improvement in the general level of animal husbandry and the increase in efficiency of the herd-owner with experience may produce trends indistinguishable from those due to selection. However, the genetic increase in yield may be estimated from the selection known to have been practised and a knowledge of the heritability. In the paper mentioned above [2], such methods were developed and applied to the selection in an individual herd. Since then Mahadevan has applied the method to estimate the genetic improvement due to culling in a group of pedigree Ayrshire herds [3]. In this paper we present the results of an investigation into the amount of selection for milk yield practised by breeders, and an estimate of the genetic gain which should have resulted from it.

Collection of the data.—The herds whose records are used in this work were originally chosen for another purpose because of their high yield. Some, though by no means all, are well-known bull-breeding herds. The twenty-two herds belong to seven breeds: Ayrshire, Friesian, Guernsey, Jersey, Red Poll, Shorthorn, and Kerry. With the exception

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of the Kerry herd (the one discussed in the original paper) the herds were recorded under the senior scheme of the National Milk Records Association, and we have used these records in our investigation. We should like to take this opportunity of thanking all those breeders who have so kindly put their records at our disposal, and in many cases allowed us to borrow their record books.

Effect of culling.—In the absence of progeny testing, the process of selection in dairy cattle may be divided into two parts, the selection of cows whose daughters will be accepted into the herd, and the selection of cows whose sons will be used in the herd or will be sold to other herds. As the number of bulls in use at any time is small relative to the number of cows, the intensity of selection in the second part is usually much higher than in the first. We shall consider the two separately.

The selection of the dams of future heifers is the result of the continuous culling that takes place. A cow is more likely to leave daughters in the milking herd if she survives for ten lactations than if she survives for only two. There is, however, not a strict correspondence between culling and selection of dams of heifers; for example, all the calves a cow has may be bulls, or the breeder may save the daughters of a cow that he has culled at an early age. As a result of culling, the cows surviving in the herd for another lactation usually have a higher average yield than the population from which they were saved. This difference we shall refer to as the culling differential. The values obtained for this are given in Table 1. In this calculation, as indeed for all others in this

TABLE 1. *Phenotypic Selection for Milk due to Culling*

Lactation	*No. of cows*	*No. culled %*	*Selection as % of milk yield*
1	1,586	27·7	+2·90
2	1,274	35·4	+3·97
3	899	35·2	+4·15
4	490	32·2	+2·57
5	365	36·7	+1·11
6	239	49·4	+0·01
7	121	47·1	+3·05
8	79	50·6	−0·02
9	35	74·3	+6·06

paper, we have excluded all lactations that might have been affected by disease and also all lactations of less than 200 days. The Table sets out the number of cows in each lactation, the proportion culled, and the culling differential. In order to combine the values for the different herds, all lactations have been expressed in terms of the herd mean for that lactation. Thus 490 cows had a fourth lactation, 32·2 per cent. were culled, and the remainder had an average yield 2·57 per cent. above the average of all fourth lactations. It will be noted that the proportion of cows culled each year increases as the cows get older, presumably because of the increase in the wastage rate from infertility and disease. The culling differential is highest in the second and third lactations, and

then declines. The figures for later lactations are rather variable because of small numbers.

The effect of culling in terms of its contribution to genetic improvement can be calculated only by weighting the yields of cows according to the number of their daughters which come into the milking herd. We must also pay regard to the number of lactations on which a cow's merit can be judged. The more lactations a cow has, the more accurate will be the estimate of her breeding-value. The genetic superiority of dams of heifers over their contemporaries is then given by

$$I = \frac{\sum nh_l^2(Y_l - \overline{Y})}{\sum n}$$

where h_l^2 is the heritability based on l lactations, $\overline{Y}$ is the mean of the first lactations of the whole herd, Y_l is the mean of the lactation yields (corrected to first lactation) and n the number of daughters which come into the herd for each cow. The heritabilities assumed are given in Table 2.

TABLE 2. *Heritability of Yield*

No. of records averaged	*Heritability milk yield*
1	0·25
2	0·33
3	0·37
4	0·40

They have been calculated on the assumption of a heritability and repeatability of a single record of 0·25 and 0·50 respectively. Only the first four lactations have been taken into account as it was found that further lactations added very little to the estimate based on four lactations. The age corrections used in combining the records were obtained by the paired-lactation method separately for each herd. If the repeatability is not complete, the paired-lactation method underestimates the effect of age on yield and use of the corrections makes the older cows look better than they really are. The genetic superiority will therefore be slightly over-estimated by this method. In order to obtain an unbiased sample it is necessary to exclude all cows which entered the herd after the oldest cow still milking. The results are shown in Table 3. It will be seen that

TABLE 3. *Selection for Milk Yield of Dams of Heifers*

Breed	*Genetic selection differential based on 1–4 lact.*	*No. of daughters*	*Mean yield, gals.*	*Genetic selection on 1–4 lactations as % of mean*
Ayrshire	+1·11 gals.	38	790	0·14
Friesian	+8·74 ,,	473	830	1·05
Guernsey	+10·70 ,,	170	720	1·49
Jersey	+8·07 ,,	101	690	1·17
Redpoll	−14·25 ,,	42	770	−1·85
Shorthorn	+14·40 ,,	703	640	2·25
Total	—	1,527	—	1·55

the genetic superiority of the cows from which heifers are bred is small. Averaging again for all breeds by expressing the yields in terms of the herd mean, the average genetic superiority of dams of heifers above their contemporaries is 1·55 per cent.

Selection in the breeding of bulls.—In the absence of any further selection, the culling would also affect the selection of dams of bulls by restricting the number of cows from which bulls could be bred. However, we have considered the breeding of bulls separately, and have investigated the extent to which the bulls used in pedigree herds were bred out of cows genetically superior to their contemporaries. In this case, as most of the bulls are used in herds other than that in which they were bred, we have made a distinction between bulls kept by the breeder for use in his own herd, and bulls sold. The work involved searching the herd-books for all registered heifers sired by bulls bred in the herds under investigation. The yield of the dam of each bull was then weighted by the number of registered heifers that he has sired. The results are set out in Table 4. It is clear that the bulls subsequently used for breeding

TABLE 4. *Selection for Milk Yield of Dams of Bulls*

Breed		*No. of bulls*	*No. of daughters*	*Genetic superiority of bulls' dams*	*Superiority as % of mean yield*
Ayrshire	Kept	11	267	6·44 gals.	0·8
	Sold	71	1,864	11·13 ,,	1·4
Friesian	Kept	6	212	42·61 ,,	5·1
	Sold	100	1,556	41·15 ,,	4·9
Jersey	Kept	10	235	48·49 ,,	7·0
	Sold	34	356	18·73 ,,	2·7
Shorthorn	Kept	30	714	48·59 ,,	7·6
	Sold	118	1,509	24·29 ,,	3·8
Kerry	Kept	24	251	37·68 ,,	8·2
	Sold	Not known		..	..
Total	Kept	84	1,679	..	6·2
	All	404	6,964	..	3·9

in pedigree herds are bred from cows that are considerably above the average of their herd in yield. The bulls kept by the breeder for his own use are on the average bred from better cows than the bulls that are sold. The dams of bulls kept are genetically superior to their contemporaries by about 6 per cent. The dams of all bulls bred in these herds and used in pedigree herds are genetically superior to their contemporaries only by 3·9 per cent.

Annual genetic gains.—In an earlier paper [2], such estimates of the genetic superiority of selected females were used to calculate the probable rate of genetic improvement in a closed herd. Unfortunately, we cannot use the above estimates with any confidence to calculate the average genetic improvement of breeds as a whole. Recent work on breed structure shows that a pedigree breed is divided into herds at three or four levels, the breeders in the lower levels buying bulls from herds

above them on the scale. In such a situation, it is only the genetic improvement in the top group that makes a permanent contribution to the breed as a whole. Any temporary improvement in the herds at the lower levels, as for instance by culling, is continually diluted by the use of bulls from the higher groups. The great mass of herd-owners are in fact passing over their breeding responsibilities to the breeders in the top group. To estimate the genetic improvement in the breed, we must know the selection practised in the top group. The herds included in this investigation are by no means all members of the top group of the breed in this sense, and to that extent cannot be taken as representative of that level. Mahadevan [4] has dealt with herds the majority of which are in the top breeding group, and his results are in general agreement with our own.

We have made two separate estimates of the genetic superiority of the dams of bulls, one referring to bulls kept and the other to all bulls used. It might be expected that the true value, as far as the genetic improvement of the whole breed is concerned, will lie somewhere between these two limits, but as there is no information about the genetic value of the bulls bought by the leading herds, we have calculated two rates of improvement, one based on one estimate, and one on the other. The annual genetic improvement was calculated from the genetic superiority of the parents and their average age when their offspring were born. The expression for the genetic improvement is then $\sum I/\sum L$, where I is the genetic superiority and L the average age of parents when their offspring are born, and where the I's and L's refer to the four paths by which genes are passed from one generation to the next (cow to cow, bull to cow, &c.). If we assume that no effective progeny testing is taking place, then the genetic superiority along two of the paths (from bull to cow, and from bull to bull) is zero, and the value of $\sum L$ is approximately 18 years. The expected annual improvement in yield is then $\frac{1{\cdot}1+3{\cdot}9}{18} = 0{\cdot}28$ per cent. if we take the lower estimate of I_{CB} and $\frac{1{\cdot}1+6{\cdot}2}{18} = 0{\cdot}41$ per cent. if we take the higher. For a breed averaging 800 gals. a year, this would mean an annual improvement in yield of around 2–3 gals. or 10 gals. a generation.

Discussion

As Lush has stated [1], the previous studies on the selection practised in farm animals are few and fragmentary. There is a fair amount of information on the reason for disposal of dairy cows (e.g. Wright [5], Seath [6], and Ward [7]), but very little on the actual selection taking place in culling except in the work of Seath. To the best of our knowledge there has been no previous study of the selection of dams of bulls except for our rather sketchy study of one herd. Seath studied in considerable detail the culling in 186 herds in Iowa and Kansas. His results are in general agreement with those presented here. He finds, for instance, an average culling differential of 4·1 and 3·1 per cent. for yield in Iowa and Kansas respectively, compared to our figure of 3·14 per

cent. He found that low yield was the chief cause of culling, accounting for 30·5 per cent. of all cows culled. The culling for low production generally took place in the early lactations. We disagree with him, however, in his application of his results to the estimation of the probable yearly genetic improvement in yield. He obtains a value for the genetic improvement by multiplying the culling differential (after correction for disease in certain culls) by a value for the heritability derived from the data and dividing by two. In making the last step he is tacitly making the reasonable assumption that culling affects the breeding of bulls as well as that of heifers. But the assumption that the culling differential is equivalent to a selection differential (in the usual sense of the last phrase, the phenotypic difference between animals which become parents of the next generation and their contemporaries), and his leaving the generation-interval out of account, do not seem to be justified. In terms of selection between contemporaries, the effect of the culling process is a continued selection. The older cows are the residue after several cullings and for that reason are genetically superior to the heifers in their first lactation which have not been culled at all in yield. From our data it appears that our estimate, obtained by taking into account the number of daughters which come into the herd and all lactations up to the fourth, gives a value for the genetic superiority of dams of cows I_{CC} of about half the culling differential C. Then assuming that $I_{CC} = I_{CB}$, we have for the annual genetic improvement with culling alone $\Delta G = \frac{\frac{1}{2}C+\frac{1}{2}C}{18} = \frac{C}{18}$. Seath's method on the other hand gives $\Delta G = \frac{1}{2} \times$ (heritability of a single record) $\times C = \frac{C}{8}$. The over-all effect of Seath's method of calculation is therefore to over-estimate the probable annual genetic improvement by a factor of about 2·25. We may therefore amend Seath's conclusions to 'the estimated yearly hereditary increase in herd average expected to result from the selection found in this study ranged from 11 to 17 pounds of milk'.

In this present study, we find that culling alone will give a probable annual genetic improvement of about 0·15 per cent. or 1·2 gals. at a mean level of 800 gals., which is in reasonably good agreement with our emendation of Seath's results. If we also include the selection of dams of bulls, we find a probable genetic improvement of 0·3–0·4 per cent. a year of 2–3 gals. Comparison of this figure with the 0·6 per cent. a year estimated above as the probable maximum with existing generation-lengths suggests that, in spite of the verbal emphasis often placed on other characters such as type, the selection that is being carried out on yield on the female side is about two-thirds of the possible. This may be rather a biased conclusion because of the selection of the herds in the investigation, which might be expected to place more than the usual emphasis on yield. However, Mahadevan, on a group of herds not selected primarily for yield, finds a rather higher probable annual improvement of 3·5 gals., his figure for the selection of the dams of cows being rather higher than ours. The probable improvement of 2–3 gals. a year is a good deal less than the breeder usually imagines

he can achieve. At best, the rates of improvement are exceedingly low and herds which regularly get bulls from the leading pedigree herds can be expected to be not far behind them in genetic merit.

This conclusion, of course, applies mostly to the selection that has been taking place in the last 20 or so years. There is no doubt that, with the general increase in milk recording, the emphasis on yield has been greater than it was earlier. Over the period of 20 years, therefore, in the absence of disturbing factors such as importations (which have probably been the governing factor in the Friesian, Guernsey, and Jersey breeds) we might have expected a total genetic improvement in annual yield of around 50 gals. It is doubtful whether a change of this magnitude would have been detected against the background of the changes in management level, due for instance to the immediate influence of the war and the subsequent shortages of concentrates.

We have not dealt with selection for fat-percentage because the sample of herds fat recorded was rather unbalanced (there were no Friesian herds, for instance). However, on the average, the selection for fat-percentage was slight but downward in direction. This is probably due to the negative correlation between yield and fat-percentage, which will cause selection for yield alone to result automatically in selection against fat-percentage.

Summary.—The amount of culling for milk yield taking place in some high-yielding herds of dairy cows is described, and its probable contribution to genetic improvement is discussed. The genetic superiority in milk yield of dams of cows and dams of bulls is calculated and the result used to compute the probable annual genetic gain from selection. The rate was found to be of the order of 0·3–0·4 per cent. per annum.

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INDEX

Alim, K. A., *see* Rendel, J. M.
Altona, R. E., the control of weeds in maize with selective plant-growth regulators, 26–32.
Asker, A. A., *see* Robertson, A.

Baker, R. E. D., bananas in East Africa. I. The botanical and agricultural status of the crop, 283–90.
Bananas in East Africa. I. The botanical and agricultural status of the crop, 283–90; agricultural status, 288; botanical status and history, 286–8; identity of certain varieties, 289–90; localities: Kenya, 283–4, Tanganyika, 284–5, Uganda, 284, Zanzibar, 285–6.
Barnett, A. J. G., studies on the ensilage of kale, 139–44.
Bartlett, S., the nutritive value of conophor cake-meal for young dairy stock and fattening pigs, 51–54.
Baxter, E. S., *see* Bartlett, S.
Braude, R., *see* Bartlett, S.
Brown, W. O., the cation-exchange properties of the basaltic drift soils of north-eastern Ireland, 134–8.
Buffalo, the Egyptian, studies on, 185–90. I. Average age and calving interval; age at calving, 188, 189; distributions of calving interval, lactation length, and dry period, 186–8; herds investigated, 186–7; types of Egyptian buffaloes, 185.
Buffalo, the Menoufi type of, 131–3; method of measurement, 131–2; suggested score-card, 133.
Bunting, A. H., *see* Cameron, J. F.

Cacao in the Gold Coast, iron and zinc deficiencies in, 73–86. Iron deficiency: occurrence, 73–75; symptoms, 75–76; treatment, 77. Iron-zinc deficiency, 83–84. Zinc deficiency (sickle-leaf): diagnosis, 80–82; induction, 78–79; occurrence, 77–78; symptoms, 79–80.
— progeny trials with, in the Gold Coast, 242–52; first progeny trial, 243–6, second, 246–7; new introductions, 247–9.
Cameron, J. F., pilot-scale crop costings on groundnuts, sorghum, and maize at Urambo Experimental Station, Tanganyika Territory, 265–74.
Cattle, dairy, expansion of a breed of, 191–201; grading-up system, 191–4; mechanism of breed expansion, 194–9.
—, —, extent of selection for milk yield in, 295–301; annual genetic gains, 298–9; collection of data, 295–6; effect of culling, 296–8; selection in the breeding of bulls, 298–9.
—, —, genetic gain in, through selection of dams of bulls, 291–4; material and methods, 291; results, 292–3.
Cattle, Friesian, genetic history and breed-structure of British, 113–30; grading-up system, 126–8; important herds and animals, 119–23; importations, 114–19; inbreeding, 123–6; material and methods used, 113–14.
Cloves, the sudden-death disease of, 145–59; control measures suggested, 146–8; forecast of economic implications, 155–9, of future development, 153–5; geographical distribution in Pemba, 148; individual outbreaks: frequency distribution of size of, 151–2, increase in total number of, 152–3, rate of spread of, 148–56.
Conophor cake-meal, nutritive value of, for young dairy stock and fattening pigs, 51–54; chemical composition, 51–52; experiment with pigs, 53–54, with young dairy cattle, 52–53.
Cooke, G. W., the mechanical application of fertilizers in field experiments, 160–74.
Crop costings, pilot-scale, on groundnuts, sorghum, and maize, 265–74.

Dow, P., *see* Haskell, G.

Evans, T. A., *see* Hughes, G. P.

Fertilizers, mechanical application of, in field experiments, 160–74; fertilizers tested, 165; mechanisms tested, 161–4: plate-and-scraper, 161–2, star-wheel, 162–3, vertical wheel, 163–4; rates of delivery: effect of moisture in fertilizers, 165–6, of periodicity in delivery, 170–1, of speed, 167–70, of variations in, 166–7.

[Grassland]. Phosphate reserves in old permanent pasture, 175–84 (*see also* phosphate reserves).
Grassland, productivity of, effect of plant-growth regulators upon, 104–12; effect of MCPA and DCPA upon: botanical composition, 109; grasses grown from seed, 109; newly sown leys, 105–6; permanent pastures and well-established leys, 107–8; pre-sowing application of MCPA, 106–7; practical applications, 111; treated herbage, palatability and toxicity of, 109–11.
[Grassland]. Response of an established sheep ley to dressings of sulphate of ammonia, 55–72.
—, weed control in with MCPA and DCPA (2, 4-D), 33–44; bracken, 41; buttercups, 38–39; creeping thistle, 34–36; docks, 40; ragwort, 36–38; susceptibility of grassland weeds to MCPA, 42–43.
Greenwood, M., iron and zinc deficiencies in cacao in the Gold Coast, 73–86.
— fertilizer trials with groundnuts in N. Nigeria, 225–41.

Griffiths, G. ap, factors influencing nitrate accumulation in Uganda soil, 1–12.
Groundnuts in N. Nigeria, fertilizer trials with, 225–41; gypsum, 233–6; N and P fertilizers 226 sqq.; placement, 231, 238–40; residual effects, 236–7; types of phosphate used, 231–3.
Groundnuts, sorghum, and maize, crop costings on, at Urambo, Tanganyika, 265–74; areas and times of operation, 268–71; methods of crop production, 265–7, of costing, 267–8; yields and costs, 271.

Halliday, D. J., field experiments in selective weed control by plant-growth regulators. III. Weed control in grassland, 33–44. IV. The effect of plant-growth regulators upon the productivity of grassland, 104–12.
Haskell, G., studies with sweet corn. V. Seed-settings with distances from pollen source, 45–50.
Hayfron, R. J., *see* Greenwood, M.
Hughes, G. P., response of an established sheep ley to dressings of sulphate of ammonia. I. Yields and botanical composition of herbage cut for silage and for hay, 55–64. II. Effects on chemical composition of the herbage, 65–72.

Inglis, J. S. S., a survey of pig-housing, 202–16.

Kale, studies on the ensilage of, 139–44; experimental apparatus and analytical methods used, 139–41; results, 141–3.
Khishin, S. S., studies on the Egyptian buffalo. I. Average age and calving interval, 185–90.

Mahadevan, P., genetic gain in dairy cattle through selection of dams of bulls, 291–4.
Maize, control of weeds in, with selective plant-growth regulators, 26–32; experiments in S. Africa at Bethlehem, 28–31, at Frankenwald, 26–8 (*see also* sweet-corn, 45–50).
McLaren, S. M., *see* Barnett, A. J. G.
Mentz, N. J., *see* Altona, R. E.
Mitchell, K. G., *see* Bartlett, S.
Moore, W., *see* Barnett, A. J. G.

Nitrate, accumulation of, in Uganda soil, 1–12; experimental work, 3–5, and results of, 5–11; influence on soil nitrate of: land opened from grass, 3; kraal manure, 7; mulch, 5; nitrate of soda, 5; sulphate of ammonia, 5; shade, 7; temperature and moisture, 7–9; rapidity of fluctuations in nitrate-content, 11; relation between crop and nitrate-content, 9–11; review of literature, 1–3, 12.
Nutman, F. J., the sudden-death disease of cloves and its economic and agricultural significance, 145–59.
Nye, P. H., studies on the fertility of Gold Coast soils. I. General account of the experiments, 217–23. II. The nitrogen status of the soils, 275–82.

Pal, B. P., potato-breeding investigations in India, 87–103.
Phosphate reserves in some old permanent pasture plots, 175–84; depth-distribution of P_2O_5 in soil, 177 sqq.; determination of available P_2O_5 by chemical methods, 179–80, by pot experiments, 180–3; manurial treatment of plots since 1897, 176.
Pig-housing, a survey of, 202–16; breeding- and rearing-houses, 208–12; fattening-houses, 212–13; general health, 205–6; heat-losses, 210–12; measurements made, 204–5: physical data from piggeries, 208–10; piggeries surveyed, 202–4; sows and boars, 213; temperature conditions: air, 206–7, globe, 207, surface, 207.
Posnette, A. F., progeny trials with cacao in the Gold Coast, 242–52.
Potato-breeding investigations in India, 87–103; collections of potato varieties, 89–90; crossability, 96; floral biology and pollen grains, 98–99; genetics, 95–98; problems and projects in India, 90–95: dormancy, 99–100, sprouts, 100–1, sterility, 96–98, 'tops' and eyes, 100.
Pushkarnath, *see* Pall, B. P.

Rendel, J. M., the extent of selection for milk yield in dairy cattle, 295–301.
Robertson, Alan, the expansion of a breed of dairy cattle, 191–201.
—, —, the extent of selection for milk yield in, 295–301.
—, —, the genetic history and breed-structure of British Friesian cattle, 113–30.
Robertson, Alex., *see* Inglis, J. S. S.
Rounce, N. V., technical considerations in the economic development of Sukumaland, 253–64.
Roy, B. B., the phosphate reserves of some old permanent pasture plots, 175–84.

Sheffield, F. M. L., *see* Nutman, F. J.
Sickle-leaf disease in the Gold Coast, 77–82; in South America, 82–84.
Simmonds, N. W., *see* Baker, R. E. D.
Soils in the Gold Coast, fertility studies on. I. General account of experiments, 217–23; climate and natural vegetation, 218–19; crops and farming methods, 220–2; methods of applying fertilizers, 222; soils, 220; trials, 217–18; distribution of, 219 (map). II. The nitrogen status of the soils, 275–82; experiments on the rate and time of N-application, 278–81; responses to sulphate of ammonia, 275–8.
—, the basaltic drift of NE. Ireland, cation-exchange properties of, 134–8; analytical methods used, 134; description and analysis of profiles, 135–6; interpretation of results, 136–8.
Sugar-cane culture in Queensland, recent advances in, 13–25; cane-breeding and

varietal work, 14–16; climate, 13; disease control, 23–24; pest control, 21–23; soil fertility investigation, 17–21; mineral deficiencies, 17–19; soil deterioration, 19–21.

Sukumaland, technical considerations in the economic development of, 253–64; agricultural conditions and practice, 253–4, 258; areas under crops, 256; crop yields, 258; production, 254–6; methods of increasing, 258–62, potential, 262–4; soils under cultivation, 257.

Sulphate of ammonia, response of an established sheep ley to, 55–72. Pt. I. Yields and botanical composition of herbage for silage and hay, 55–64; botanical composition of silage cuts and one hay-cut, in 1946–7, 62–64; dry-matter yields of two hay-cuts and three silage cuts in 1946, 56–59, of one hay and two silage cuts in 1947, 59–62. Pt. II. Effects on chemical composition of the herbage, 65–72; yield and percentage of crude protein in the hay and aftermath cuts, 68, 69, 71, 72, in the silage cuts, 65–68, 69, 70, 71.

Sweet corn (maize), studies with. V. Seed-setting with distances from pollen source, 45–50; experimental data, 45–48; results, 49.

Templeman, W. G., *see* Halliday, D. J.

Thomas, Brynmor, *see* Roy, B. B.

Toxopeus, R., *see* Cameron, J. F.

Vallance, L. G., recent advances in sugar-cane culture in Queensland, 13–25.

Van Keulen, B. W., *see* Cameron, J. F.

Zaki, M. H., the Menoufi type of buffalo: a suggested score-card, 131–3.